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XIX.—*A New Method of Measuring Alternating Currents and Electric Oscillations. By* I. WILLIAMS, *M.Sc., Lecturer in Physics in the University of Bristol.*

RECEIVED APRIL 26, 1918.

§ 1. Alternating currents may be measured by means of the electromagnetic, the electrostatic, or the thermal effects which they produce. At low frequencies all these effects can be used, but when the frequency is high the electromagnetic effect cannot be usefully applied on account of the excessive dielectric currents, the values of which are functions of the frequency. Up to the present the application of the thermal effect has proved the most satisfactory basis for the construction of instruments to be used for the measurement of currents of the frequencies which are in common use in wireless telegraphy. If the resistance of the conductor which is heated by the current remains constant, the rate of generation of heat is strictly proportional to the square of the current. The rate at which the heat is generated has been measured by observing (*a*) the expansion, (*b*) the change of electric resistance, or (*c*) the thermoelectric electromotive force which is produced in the wire itself or in its immediate surroundings.

In this Paper a new thermal method of measuring alternating currents and electric oscillations is proposed, and two new types of instrument are described. Type 1 is based on Crookes'* well known work on radiometers ; the heat generated by the currents in a wire causes the deflection of a mica vane suspended in a vessel, the pressure in which can be maintained at a suitable value. Type 2 is based on work done by Osborne Reynolds † ; the mica vane is replaced by a filament or narrow strip of suitable material, the deflection of which can be observed directly by means of a microscope. Type 1 may be said to resemble an electrometer, while Type 2 resembles an ordinary gold-leaf electroscope.

The method proposed has not, so far as the author is aware, been previously applied to the measurement of alternating currents and electric oscillations. When the application of this method of measurement was first considered it was thought quite possible that the attractions, which are produced at certain pressures, might be as useful, or perhaps, more useful than the repulsion effects produced at lower pressures. For this reason it was considered advisable to investigate the relative magnitudes of these quantities from atmospheric pressure down to very low pressures.

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* "Phil. Trans.," Vol. CLXV., p. 579, 1875.

† "Phil. Trans.," Vol. CLXX., p. 768, 1879.

§2. The first form of apparatus used is shown in vertical section in Fig. 1. *ABCD* is a circular brass casting which is flanged at *AD*, and supported on three levelling screws. In this casting three holes were drilled, one of which is shown at *E*; the other two were situated on a line, through the vertical axis, perpendicular to the plane of the paper. The mirror *R*

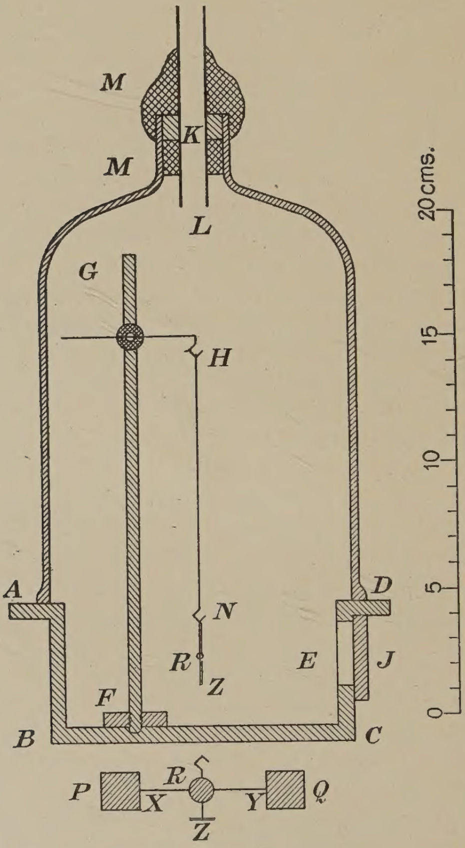


Fig. 1.—High-frequency Ammeter. Type 1.

could be observed through a plate glass window *J* and the heaters could be inserted through the other two holes. *FG* is a rod carrying a hook *H*, from which the vanes were suspended, and which could easily be adjusted to any suitable position. Resting on the casting and cemented to it is a bell-jar, in the neck of which was fixed an ebonite stopper *K* through which passed a glass tube *L*; the stopper was covered internally and externally with "Picein" at *MM*. *L* was connected to the pump and the McLeod gauge by a flexible glass connection which allowed just sufficient freedom for levelling.

The vanes *P* and *Q*, which were each about 15 mm. square, were made of very thin mica and were blackened on the faces exposed to radiation from the heated wire; they were suspended from the hook *H* by a quartz fibre which was about 10 cm. long. *XY* is a very thin glass capillary and *Z* is a very small light magnet; the hooked mirror carrier was made of aluminium. The heaters were made of a nickel-chrome alloy. Two heaters were provided so that they could be made to deflect the vanes in the same, or in opposite, directions.

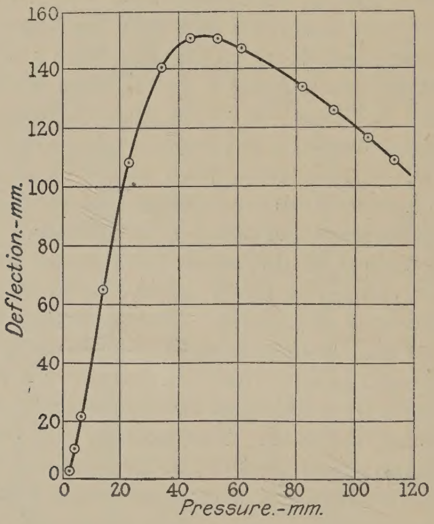
The observations of deflection were made by means of a telescope and scale, the latter being placed at a distance of about 120 cm. from the mirror. The apparatus was protected from draughts and from external radiation by means of cardboard screens and cotton wool. In front of the window *J* was a screen pierced by a hole just large enough to permit of the deflection being observed. The heating coil was connected to earth and the upper part of the apparatus was earthed, as far as possible, by layers of wire gauze on the outside.

The high-frequency current can be measured (1) by observing the deflection and using a calibration curve obtained with direct current, or (2) by a Null method. In the second case, a first balance is obtained when the same direct current of known value is passed through the two heaters in series, in such a direction as to tend to deflect the two vanes in opposite directions; then, a second balance is obtained when the high-frequency current flows through one heater and the direct current through the other heater is adjusted until the vane is again in the same position.

§ 3. The observations over the pressure range 1·45 mm. to 113 mm., the value of the heating current being 0·5 ampere, are recorded in Table I. and plotted in curve 1. The attraction rose rapidly to its maximum value at about 45 mm., and then decreased more slowly over the remainder of the range.

TABLE I.—*Mica Vane A. Attraction.*

Pressure. Millimetres.	Deflection. Millimetres.	Pressure. Millimetres.	Deflection. Millimetres.
1·45	0·0	44·0	150·5
2·08	3·0	53·0	150·0
4·08	10·0	61·0	147·0
6·08	21·5	82·0	133·5
14·0	64·5	93·0	126·0
23·0	108·5	104·0	116·5
34·0	140·5	113·0	109·0



CURVE I.

The heating current was now varied from 0·1 ampere to 0·5 ampere, while the pressure was maintained constant at 33 mm. The observations indicated that the deflection of the vane was very accurately proportional to the square of the current.

§ 4. When observations were made at lower pressures leakage troubles arose, and as it was suspected that the leak took place at the circular surface of separation between the brass casting and the bell-jar, the form of apparatus described above was abandoned for the present in favour of a form constructed entirely of glass, a vertical section of which is shown in Fig. 2.

ABCD is a hollow cylinder which has ground flanges at each end and ground joints in the vertical tubes *E* and *F*. The vane suspension passed through *E* and the leads to the heater through *F*. The end *AB* was closed by a piece of plate-glass 0·5 in. thick and the end *CD* by a bell-shaped tube *CDP*. The joints at the ends *AB* and *CD* were cemented with "Picein."

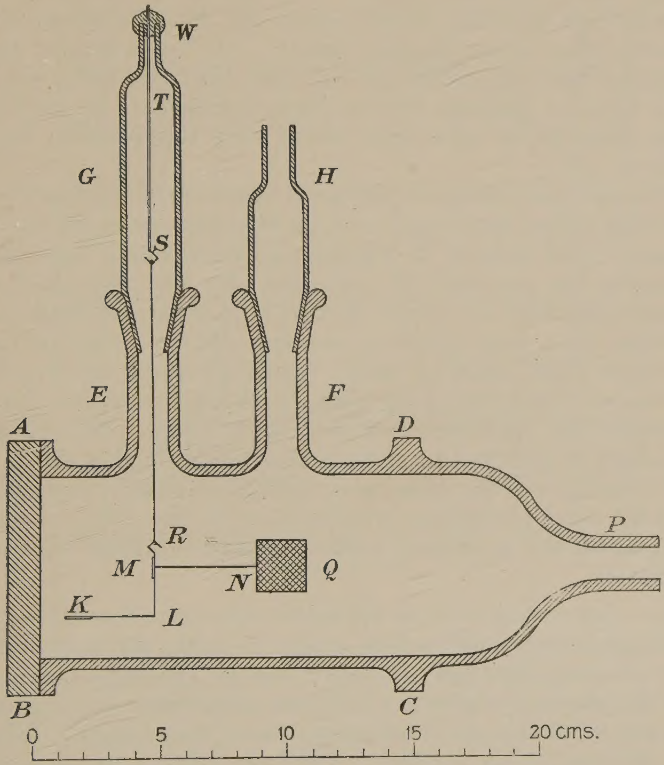


FIG. 2.—HIGH-FREQUENCY AMMETER. TYPE 1.

The vane *Q* was a rectangular plate of very thin mica, 20 mm. × 20 mm., blackened on the side exposed to radiation from the heated wire. *K* was a damping plate made of very thin copper foil, which could move over the pole of a magnet not shown in the figure. *KL* and *MN* were short light glass capillaries, while *RML* was an aluminium wire to which the mirror *M* was attached.

The heater was a short straight length of platinum wire which had a resistance of about 0·9 ohm. The two leads passed out through the ground joint in *F* and were insulated from one another by glass tubing. The heater was kept fixed while the vane could be adjusted to any suitable distance from it by rotating the tube *G*.

The whole arrangement was mounted on a levelling table, which stood on a brick pillar. The end *P* was connected to the storage chamber, Gaede pump, and McLeod gauge by a flexible glass connection as before. The observations were made by means of a telescope and scale, the latter being placed at a distance of about 120 cm. from the mirror. Everything was mounted on slate slabs which were supported by brick pillars.

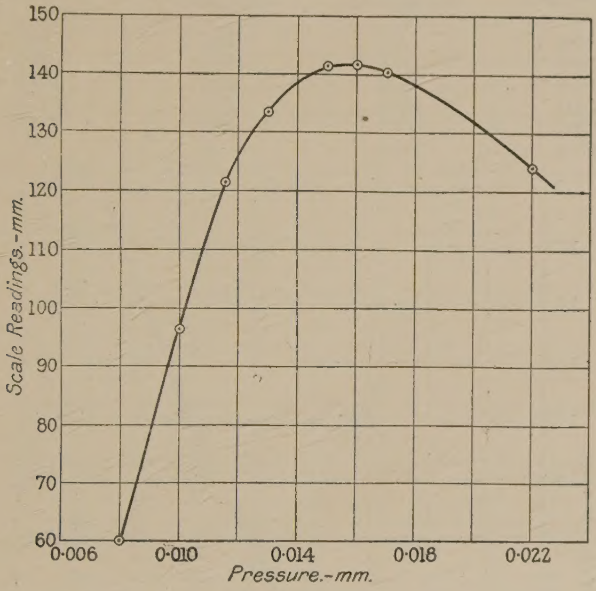
The gas used for the experiments passed over fused calcium chloride before entering a storage chamber where it was in contact with a layer of phosphorus pentoxide; from this chamber the gas could be admitted into the apparatus in small quantities by means of two taps separated from one another by a short piece of capillary tubing; the working pressure could thus be easily varied by small increments. A second vessel containing phosphorus pentoxide was placed between the apparatus and the Gaede pump. All the gas admitted to the apparatus could thus be thoroughly dried.

The heater and the vessel were earthed, as already described, and the same precautions were taken, as in the previous case, to protect the apparatus from draughts and from external radiation.

§5. The second form of apparatus was quite free from the leakage troubles which had arisen in using the first form. Dry air was repeatedly pumped through the apparatus and the dry air at low pressure had been standing in it for about a week before the recorded observations were made. When the pressure in the apparatus had been reduced to a suitable value by the Gaede pump and an electric current which remained absolutely constant was passed through the heating coil the reading on the scale was observed; a suitable quantity of dry gas was then admitted from the storage chamber and the scale reading again observed, and so on. The results obtained for the pressure range 0·008 mm. to 0·022 mm. are given in Table II. and curve 2 for a current of 0·1 ampere. The repulsion reached its maximum value at a pressure of about 0·0155 mm.

TABLE II.—*Mica Vane B. Repulsion.*

Pressure. Millimetres.	Scale reading. Millimetres.	Pressure. Millimetres.	Scale reading. Millimetres.
0·008	60·0	0·015	141·2
0·010	96·3	0·016	141·2
0·0115	121·5	0·017	140·2
0·013	133·5	0·022	124·0



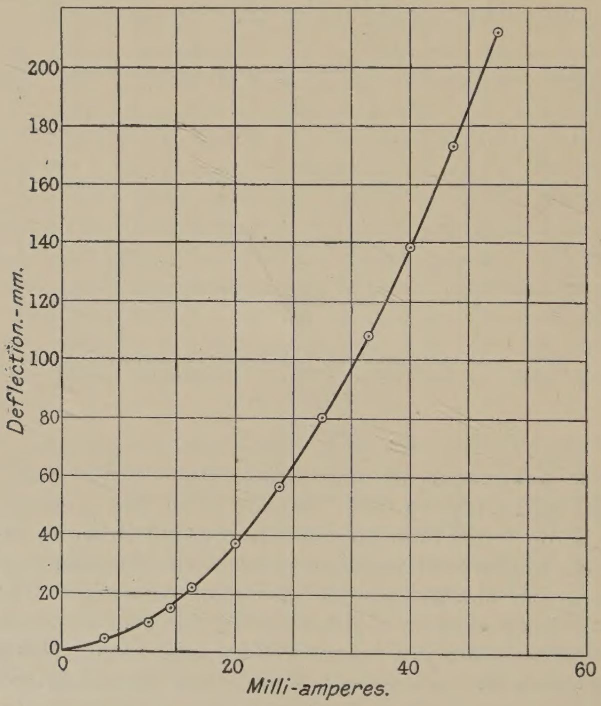
CURVE II.

In the next series of observations the current was kept constant and equal to 0·077 ampere while the pressure was varied from 0·020 mm. to one atmosphere in order to get some idea of the relative magnitudes of the repulsions at low pressures and the attractions at higher pressures. The repulsion decreased at first fairly rapidly, and then more slowly, until it became zero at a pressure of 4·6 mm. From this point the repulsion at first increased and then decreased to zero again at 288 mm. Over the pressure range 288 mm. to one atmosphere the vane was subject to an attraction which increased in value up to atmospheric pressure. As the apparatus was designed for work at pressures below one atmosphere no observations were made at pressures greater than atmospheric.

§ 6. The pressure was now reduced to 0·014 mm. and the current varied from zero to 50 milliamperes. The values obtained are given in Table III. and curve 3. Table IV. and curve 4 indicate the results obtained, for a pressure of 0·016 mm.

Table III.—*Mica Vane B.*

Current. Milliamperes.	Deflection. Millimetres.	Current. Milliamperes.	Deflection. Millimetres.
5·0	4·2	30·0	80·5
10·0	10·2	35·0	108·2
12·5	15·0	40·0	139·0
15·0	22·0	45·0	173·5
20·0	37·5	50·0	212·0
25·0	56·5	—	—

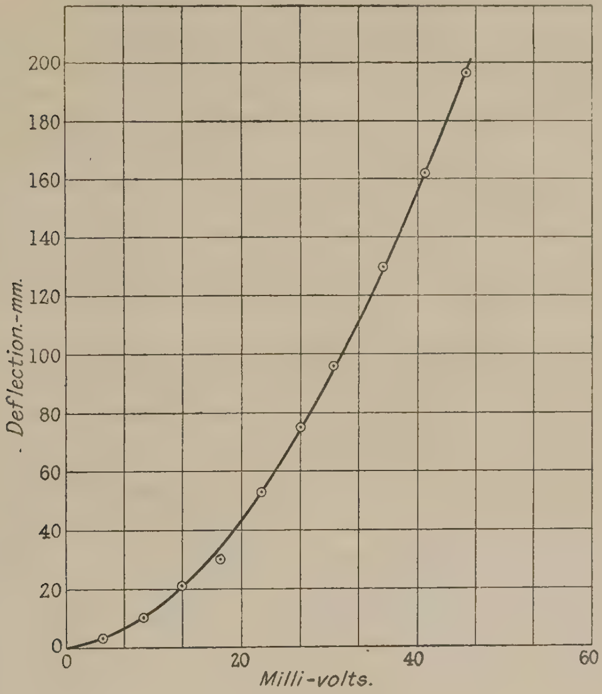


Curve III.

when the instrument was used as a millivolt meter. A current of 5 milliamperes gave a deflection of 4·2 mm., whilst a potential difference of 4·4 millivolts gave a deflection of 3·8 mm.

TABLE IV.—*Mica Vane B.*

Potential difference. Millivolts.	Deflection. Millimetres.	Potential difference. Millivolts.	Deflection. Millimetres.
4·4	3·8	26·8	75·3
8·9	10·3	30·5	96·0
13·2	21·0	36·0	129·8
17·6	30·0	40·8	162·3
22·2	53·0	45·6	197·0



CURVE IV.

§ 7. The same heater was used in carrying out the experiments, the results of which are given in Tables II., III. and IV. The tables and curves indicate that the maximum deflection, for the apparatus used, is obtained at a pressure of about 0·015 mm. The deflection due to repulsion at this pressure is roughly about six times as great as the deflection due to attraction at atmospheric pressure. Curves 3 and 4 indicate that the instrument is quite satisfactory as an ammeter or voltmeter. The sensitiveness for currents which is indicated by curve 3, viz., 4·2 mm. for 5 milliamperes can obviously be increased to a very considerable extent. The resistance of the heater used was only 0·9 ohm. Since the heating effect is proportional to the product of the resistance and the square of the current the sensitiveness can obviously be raised by using heaters of higher resistance, and experiments are now being carried out with a view to designing a suitable series of different magnitudes.

The fibre used for the suspension of the vanes was a home-made one, and later experiments have shown that this fibre was rather coarse. The sensitiveness can be increased by replacing this fibre by a fibre which is thinner and somewhat longer.

The mirror used was an ordinary galvanometer mirror 10 mm. in diameter and weighing about 100 milligrams. The weight of this mirror was a very considerable fraction of the weight of the moving parts. Here again the sensitiveness can be increased by using a mirror weighing say 20 milligrams ; such mirrors are supplied commercially at a moderate price.

The instrument is suitable for large and small currents, as the sensitiveness can be varied by (1) change of heater, (2) change of control, or (3) change of vanes.

Unless suitable precautions are taken, instruments of this type are subject to considerable changes of zero. It is essential to shield them as completely as possible from extraneous radiation ; this was done by surrounding the instrument with a thick layer of cotton wool, leaving uncovered just sufficient window area to permit of readings being made with a telescope and scale. When it is necessary to illuminate the scale, by means of a lamp, for work at night, the lamp must be screened.

Dellinger* has discussed very fully the arrangement of circuits in high-frequency ammeters having one or more hot wires. If one hot wire or strip is used the leads should be brought in perpendicular to the ends of the hot wire. For convenience in carrying out the present experiments the leads have not actually been introduced in this way, but the apparatus can easily be modified slightly to permit of this being done. The shape of the apparatus shown in Fig. 2 is a matter of accident ; this particular glass vessel, which had been constructed for other work, was immediately available and was used because of the difficulty in getting new apparatus constructed in reasonable time. In the apparatus now in course of construction, the high-frequency current enters and leaves at two points which are a considerable distance apart ; the mass and the moment of inertia of the moving system have also been considerably reduced. In discussing branch circuits Dellinger (*loc. cit.*, page 93) points out that "when the indicated current depends on the heat production in just *one branch* (of a multi-wire instrument) the error due to change of current distribution on high frequencies may be very great. When the indicated current depends on the heat production of the *whole* current, the error will be of a smaller order of magnitude, but may be appreciable when the change of current distribution is great, inasmuch as the total heat production in any system increases as the distribution on direct current is departed from." In the method of current measurement proposed in the present Paper the heat production of the whole current is utilised, and the errors which arise are thus kept as low as possible.

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* "Bulletin," Bureau of Standards, Vol. X., p. 91, 1914.

§ 8. Experiments have also been carried out with an apparatus of the electroscope form, referred to above as Type 2, and shown in Fig. 3. It was shown by Osborne Reynolds * in his discussion of the movement of Crookes' vanes and allied problems that a silk fibre suspended in an exhausted tube is subject to forces of the same nature as those acting on the vanes of a radiometer. Reynolds also showed experimentally that when the silk fibre was exposed to radiation from an external source it was repelled over the pressure range 0·6 mm. to 200 mm. and attracted over the range 200 mm. to one atmosphere. It seemed clear, that if the deflection of the Crookes' vanes could be used for current measurement, the motion of a fibre could also be used for the same purpose.

A silk fibre *AB* about 75 mm. long attached to the end *A* of a metal rod *AC* which could slide up and down, rotate about, or be moved to or from the vertical rod *CD*. The latter was mounted on an ebonite block *DEF* and connected to one terminal *G* and also to earth. Starting from the terminal *G*, the heated wire *GH* passed over a hook at *H*, over two more hooks not shown, and finally was clamped to the terminal *G′* immediately behind *G*.

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* "Phil. Trans.," Vol. CLXX., p. 768, 1879.

The ebonite block *DEF* with its heating coil and fibre was mounted in the lower half of a wide vacuum tube *XYZ*, the leads to the terminals at *GG′* being cemented in at *Z* and insulated from one another by a glass tube. The end *X* of the tube was permanently connected to the McLeod gauge, storage chamber, and Gaede pump, as in previous work.

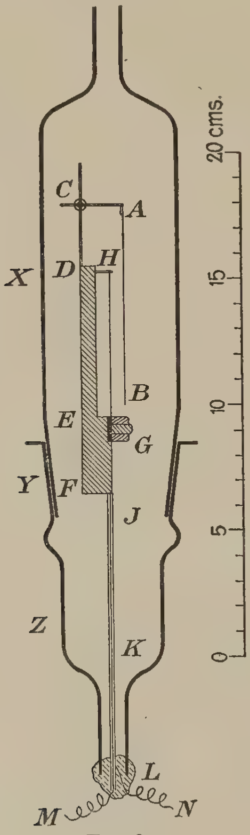


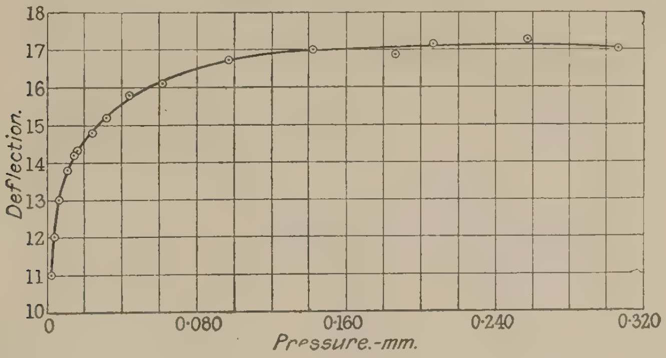
Fig. 3.

By means of the ground joint at *Y*, the whole arrangement could be taken out and the fibre or the heating wire changed or adjusted. When a current was passed through the wire *GH* the motion of the end *B* of the fibre was observed by means of a microscope having an eyepiece scale. The microscope available for the work was not a particularly good one, as the magnification was very low, being only about nine.

§ 9. The apparatus was pumped out repeatedly, as in the previous work, and then filled with dry air from the reservoir. Before the observations recorded in the tables were made the dry gas had been standing in the apparatus for some days. The pressure was reduced as far as possible and the deflection of the fibre was then observed for various pressures from 0·002 mm. to 2·94 mm., the current being kept constant and equal to 0·05 ampere. These observations are given in Table V.

Table V.—*Silk Fibre. Repulsion.*

Pressure. Millimetres.	Deflection.	Pressure. Millimetres.	Deflection.
0·002	11·0	0·186	16·9
0·004	12·0	0·206	17·1
0·0065	13·0	0·258	17·2
0·011	13·8	0·306	17·0
0·016	14·3	0·39	16·8
0·015	14·2	0·48	16·3
0·024	14·8	0·72	14·8
0·032	15·2	0·97	13·6
0·044	15·8	1·66	10·7
0·071	16·1	2·38	8·8
0·097	16·7	2·94	7·6
0·142	17·0	—	—

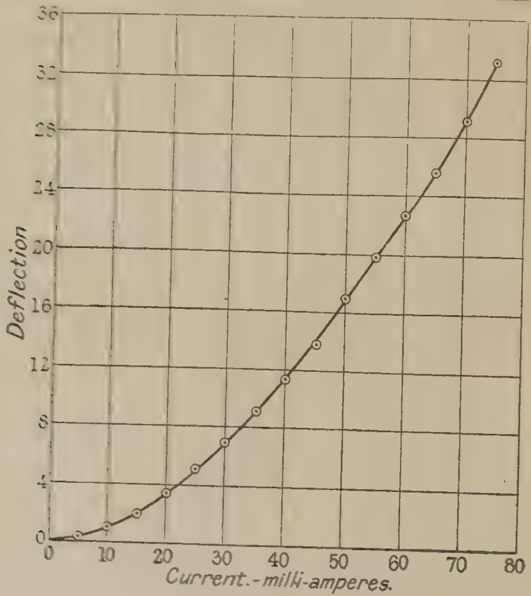


Curve V.

The zero was very steady and the deflection for a given current and a given pressure could be repeated over and over again. The return to zero was very rapid. The following numbers illustrate the behaviour of the fibre apparatus in this respect very well:—(1) Current of 50 milliamperes switched on gave a reading of 57·0 ; 15 seconds after break the reading was 73·5 : and in 30 seconds the reading had reached 74·0 and remained steady. (2) Same current switched on again the reading was 57·0 ; 15 seconds after break it was 73·5 ; and in 30 seconds it was 74·0. (3) The same current was switched on a third time ; the reading was again 57·0 ; 10 seconds after break it was 73·0 ; in 20 seconds it was 73·8 ; and in 25 seconds it was 74·0.

TABLE VI.—*Silk Fibre.*

Current. Milliamperes.	Deflection.	Current. Milliamperes.	Deflection.
5·0	0·3	45·0	13·7
10·0	1·0	50·0	16·9
15·0	1·8	55·0	19·8
20·0	3·4	60·0	22·7
25·0	5·0	65·0	25·6
30·0	6·8	70·0	29·2
35·0	9·0	75·0	33·2
40·0	11·2	—	—



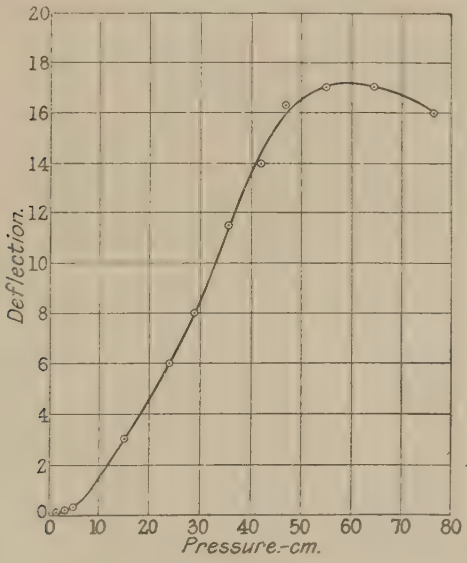
CURVE VI.

It is clear from Table V. and curve 5 that within the pressure range 0·002 to 3 mm., the repulsion reaches its maximum value at a pressure of about 0·28 mm. Between 0·1 mm. and 0·4 mm. the curve is very flat and obviously the instrument can be used as a current measurer at any pressure between these limits. That the maximum repulsion should be reached in the case of a thin filament at a much higher pressure than in the case of the vane is in accordance with Reynold's theoretical conclusions; the narrower the body the higher the pressure at which the repulsion effect is a maximum.

TABLE VII.—*Silk Fibre. Repulsion.*

Pressure. Centimetres.	Deflection.	Pressure. Centimetres.	Deflection.
1·4	1·0	35·5	11·5
3·1	1·3	42·0	14·0
4·7	1·4	47·0	16·3
15·0	3·0	55·0	17 0
24·0	6·0	64·0	17·0
29·0	8·0	76·0	16·0

Current=0·05 ampere.



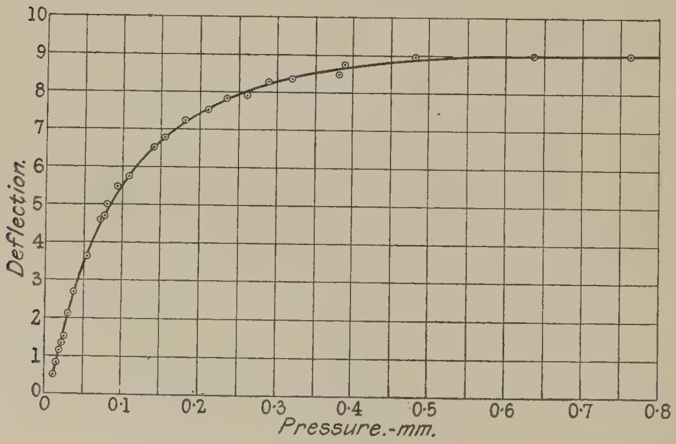
CURVE VII.

The pressure was next maintained constant at 0·28 mm., while the current was varied from 0 to 75 milliamperes; the current was measured with a Siemens milliammeter as before. The results are given in Table VI. and curve 6. As shown above the instrument possesses the following desirable qualifications for making a good ammeter: (*a*) steady zero and (*b*) rapidity in action.

TABLE VIII.—*Quartz Fibre B. Repulsion.*

Pressure. Millimetres.	Deflection.	Pressure. Millimetres.	Deflection.
0·010	0·5	0·142	6·5
0·015	0·8	0·156	6·8
0·017	1·1	0·180	7·2
0·020	1·3	0·210	7·5
0 025	1·5	0·235	7·8
0·031	2·1	0·26	7·9
0·041	2·7	0·29	8·3
0·053	3·6	0·32	8·4
0·069	4·6	0·38	8·5
0·074	4·7	0·39	8·8
0·080	5·0	0·48	9·0
0·094	5·3	0·64	9·0
0·110	5·7	0·76	9·0

Current=0·1 ampere.



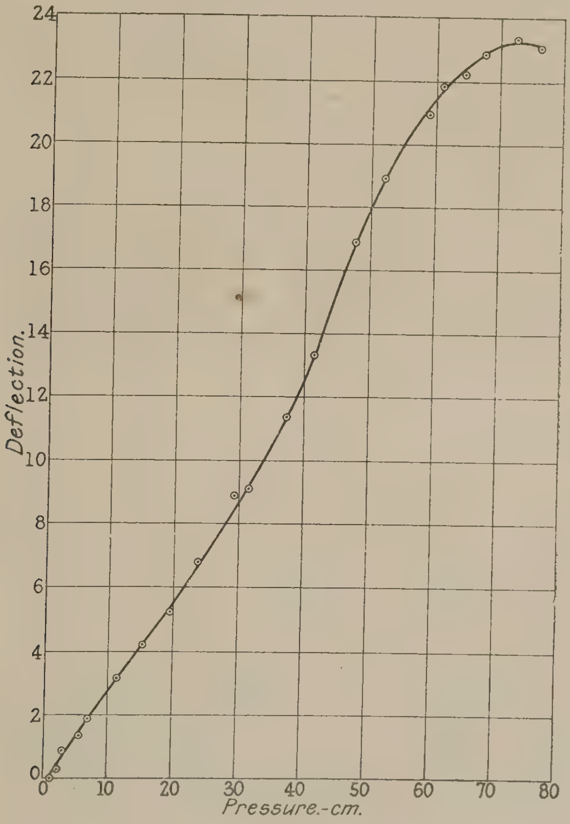
CURVE VIII.

Over the pressure range 1·4 mm. to one atmosphere, the deflection reached its maximum value at a pressure of about 60 cm. as shown in Table VII. and curve 7. These results

TABLE IX.—*Quartz Fibre B. Attraction.*

Pressure. Centimetres.	Deflection.	Pressure. Centimetres.	Deflection.
1·5	0·0	37·4	11·4
2·3	0·3	41·4	13·3
3·4	0·9	47·6	16·9
5·8	1·4	52·2	18·9
7·2	1·9	58·7	21·0
11·5	3·2	61·1	21·8
15·5	4·2	64·6	22·2
19·7	5·2	67·7	22·8
24·0	6·8	72·6	23·3
29·5	8·9	76·4	23·0
31·6	9·1	—	—

Current=0·03 ampere.



CURVE IX.

differ from those of Reynolds in that a repulsion was observed with the silk fibre for all pressures from 0·002 mm. to one atmosphere. The deflection at atmospheric pressure is of the same order as that obtained at 0·28 mm. So far as one can judge at present the instrument is more steady in its behaviour at low pressure than at atmospheric pressure.

§ 10. *Glass Fibres.*—A number of fine glass fibres were drawn out and the thinnest one selected. This was mounted in the apparatus with the intention of making a similar set of determinations for glass; but the fibre was too coarse and stiff and the deflections were too small to be dealt with by the microscope available. With a microscope of higher power there would be no difficulty in using glass fibres.

§ 11. *Quartz Fibres.*—The quartz fibre *A* used for the early experiments was home-made. It was rather coarse and stiff, but a complete set of observations was obtained by means of it. This fibre was replaced by fibre *B* made by the Cambridge Scientific Instrument Co., and the observations given in Tables VIII. and IX. and curves 8 and 9 are those obtained with fibre *B*.

The observations showed that the variation of the deflection with pressure was somewhat similar to that observed in the case of the silk fibre. The curve was practically flat over the pressure range 0·4 mm. to 0·8 mm. The repulsion decreased to zero at a pressure of 1·5 cm., and from this point to atmospheric pressure the fibre was attracted. The attraction seemed to approach a maximum at atmospheric pressure, as shown in curve 9. Observations made with the same current over the whole pressure range indicated that the magnitude of the attraction, at atmospheric pressure, was about 16 times as great as that of the maximum repulsion over the lower pressure range.

In the case of quartz, a deflection current-curve is not given in this paper, as some irregularities arose the sources of which have not yet been traced definitely.

This work is still going on. In the case of Type 1 the question of suitable heaters is being investigated. As regards Type 2 preliminary work has been done with spider threads and gold leaf, and the quartz fibre is being further investigated.

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ABSTRACT.

The method consists of the application of the Crookes and Osborne Reynolds radiometers to the measurement of the R.M.S. values of electric currents. Two types of apparatus are described. In the first of these the heat generated by the passage of the current through a nichrome resistance causes the deflection of a light mica vane attached to the extremity of a suspended beam. In the second type the deflection of a fine fibre is employed. Tables and curves are given connecting the indications of the instruments with the current and with the degree of evacuation.

DISCUSSION.

Mr. G. D. **West** said that in his Paper on the Measurement of the Pressure of Light by the deflection of a thin metallic strip he had called attention to certain disturbances due to gas action. He treated them at that time as sources of error, but had since been engaged on their investigation. He could not go into his results here, but would just like to say that some of the effects shown by the author were not wholly explicable by the Crookes radiometer effect. He would also like to point out that Knudsen had studied the deflection of strips placed close to an electric heater. There were possibilities of the useful application of some of these effects when they were properly understood. At present, however, there was considerable uncertainty in connection with some of them.

Dr. **Sumpner** thought the instrument described by Mr. Williams was likely to prove a valuable one. Comparatively little information was given concerning the heaters, so it was difficult to judge of their suitability for the currents employed in wireless telegraphic work, which were very much smaller than those mentioned. There was the danger that if the resistance had to be made too high the instrument would alter the magnitude of the current it had to measure.

Prof. **Howe** said that one of the difficulties in measuring high-frequency oscillations was the effect of electrostatic forces between the heater and the thing heated. It appeared to him that this type of instrument was particularly liable to this source of disturbance. An obvious way to overcome this was to put a dummy heater on the other side of the vane or fibre and put it in electrical connection with the heater. He thought that in its present form the instrument could not be very convenient in use

Dr. D. **Owen** said he was not certain that the difficulties inherent in the measurement of minute forces had all been surmounted. From Table I. it would appear that they had, as in this case the deflections were stated to be accurately proportional to C^2. This law was not, however, followed in Table III., the deflections being all smaller than they should be, despite the fact that a platinum heater was used in this case, which would lead one to expect too high readings. He observed that the author connected the heater to earth, and gathered from this that electrostatic disturbances had been noticed. It was not easy to apply this method of elimination of these effects in the case of high-frequency oscillations.

Dr. W. **Eccles** said that some years ago he had built a little apparatus which would detect a microampere. The heater was a short glass fibre platinised. It was mounted about 2 mm. below the extremity of a light horizontal fibre of quartz, which constituted the beam of a delicate micro-balance. The effect was best at atmospheric pressure, and he had always attributed it to convection currents; but it seemed that there might be many other factors entering into it. The heater was of about 1,000 ohms, so that the value of the watts consumed per micro-ampere was 10^{-9}. He also made another type, in which a light vane was mounted at the end of the beam. This was several times as sensitive as the first. He had described these in one of his Papers at the time.

Prof. LEES asked how the pressure was maintained sufficiently steady, as the sensitivity appeared to vary considerably with the pressure.

Mr. WILLIAMS, in reply, said he had had no difficulty with pressure. The change of sensitivity with pressure was small near the top of the curve, at which he usually worked. This question did not, of course, arise at all when employing the Null method. He had not seen any of Knudsen's work when he started these experiments, and originally intended to use the instrument as a manometer, as it was suitable for measuring very small changes of pressure due to leakage or transpiration through substances. He subsequently found, however, that Knudsen's work already covered this ground. With regard to Dr. Sumpner's remarks on the magnitude of the current, it had to be borne in mind that the instrument described was an experimental one, and could be very much improved by reducing the inertia of the suspended system and using a much finer suspension. With regard to the square law, the graph in the Paper applied to the first type of instrument only; he thought Dr. Owen's remarks applied to observations made with the other type. As regards electrostatic disturbances, he thought at first he detected effects of this kind, but found they were unaffected by the proximity of radium. He had subsequently found them to be mostly due to other causes.

An Exhibition of Coupled Vibrations was given by Prof. E. H. BARTON, *F.R.S., and Miss* H. M. BROWNING.

THE apparatus shown consisted of a pair of pendulums, each of which was suspended from the mid point of a sagging string, the direction of which was transverse to the direction of oscillation of the pendulums. The two sagging strings were connected by a light wooden rod at the points from which the bobs were suspended. Each bob consisted of a metal funnel, from the apex of which a fine stream of sand fell during an experiment. A horizontal board could be moved slowly on rails just below the oscillating bobs, and the fine sand falling on this gave curves showing their motion. When one bob is set in oscillation the other being initially at rest, the latter, as is well known, starts to vibrate with gradually increasing amplitude until the first bob has been brought to a standstill, when the process is reversed. From an examination of the equations of motion it is found that the amount of sag in the transverse strings governs the degree of "coupling" of the oscillators, and by varying this and also the relative mass and periods of the pendulums, curves can be obtained illustrating all the phenomena of coupled electrical oscillations. By stopping one of the bobs when it has just been reduced to rest, thereby preventing the energy from being reabsorbed by it, the conditions of the quenched spark can be imitated.

THE TEACHING OF PHYSICS IN SCHOOLS.

A MEETING of the Society was held on Friday, June 14, 1918, at the Imperial College of Science, South Kensington, when a discussion took place on "The Teaching of Physics in Schools." The chair was taken by the President, Prof. C. H. LEES, F.R.S.

The PRESIDENT said: This meeting is the outcome of a desire on the part of the Physical Society to help those of its members who are engaged in science teaching, especially those engaged in teaching in public and secondary schools, to carry out the probable extension of that teaching which will ensue in the course of the next few years. At the present time there is a great demand throughout the country that the average well-educated man shall know more physics in the future than he has known hitherto, and the physics teachers will have to play their part in furthering that advance. With these explanatory remarks, I will call upon Sir Oliver Lodge to open the discussion.

Sir OLIVER LODGE, Principal of the University of Birmingham, said: Mr. President, I very much agree with your observations that it is desirable that the average man shall know more physics than he does at present. He could hardly know less. But I do not quite know why I should have been selected to open the discussion (except that it may be thought that I should at any rate not close it), because there was no teaching of science in schools when I was young. I hardly knew what science was until I had left school, and I never took part in school teaching. I have taught in universities all my life, but university teaching is comparatively easy, and is outside our subject this afternoon. What I am impressed with is that the teaching of science in schools is a very difficult task. I have read through the Papers which have been circulated before the meeting, and I think there is a large amount of wisdom in them. I should suppose that any teacher who seriously set to work to think about the teaching of his subject, and was keen enough to read a Paper on the methods of teaching it, was likely to be a good teacher. I expect there are lots of methods of teaching, and, as Kipling would say, "every single one of them is right," provided they are the outcome, not only of knowledge, but of enthusiasm for the subject. That seems to me to be about the most essential part of the business. Curricula are minor things in comparison, and yet they must exist, and no doubt some curricula are better than others.

Now, in speaking to an audience of specialists it is unnecessary to be elaborate or long, and since there are many speakers we shall all have to be short ; I will try to set a good example. In the first place, we must discriminate between the teaching of science to specialists, or to those who are going to be specialists in the subject, and, on the other hand, the teaching of science as a branch of general education. The first is much easier than the second. If you are teaching boys who have a liking for physics, almost any method of teaching will do. But if you are teaching science as a branch of general education to those who are going to be classical scholars or literary people, or people not specially scholars at all, then you have to interest them in the subject—they may not be naturally interested—and you must avoid making it repulsive to them. And I think that what you need from the point of view of general education, which after all is required by the majority of boys, is to take a wide scope—a wide survey, without emphasising too much the details, or, rather, emphasising the details precisely and accurately in a small branch of the subject, and covering a much greater area widely and generally. The same sort of thing is necessary in classics, too ; the hole-and-corner strict grammatical method without any key or note was a severe grind and discipline, but it did not teach one literature ; it was merely a language grind. That is proper and good up to a point, but it should not be the whole ; it is not a classical education. The large survey of literature, whether in translations or otherwise—in translations whenever necessary—should be employed as well ; and that represents, in a sort of parable, what is true also of science.

I should like to call attention to the recent report of the British Association Committee on science teaching, which, I suppose, is well-known to all of you ; there are some excellent Papers in that report, but there are one or two—especially one at the end—with which I to some extent find myself in doubtful agreement, or, I might say, in disagreement, except that I am not an expert in school teaching. And yet there is a sort of truth about it, too. The thesis is that you should begin by dealing with common objects. Take any common object and analyse it down to principles, do not begin with the principles and build up. That is to say, employ the method of analysis—the analytic method rather than the synthetic method. I think that the wise policy is to run the two together, but it depends a great deal upon whether you are dealing with adults or with children. If you are dealing with adults, as Prof. Perry was, for instance, in the evening classes at Finsbury, you may do as he did, and take a gas engine or a steam engine or anything to which the men are accustomed in their daily work, and analyse out the principles of it, working down to thermodynamics from the engine if you can. That method is possible with adults, though I think difficult, and requiring some genius in the teacher, but it is unsuitable for boys. There you must begin with elementary principles and build up; not, however, keeping the steam engine in the background—let them attend to that as much as they like, but do not make it the basis of your education. And what I have said about the steam engine applies to all sorts of common objects. What I feel about common objects is that they involve too much mathematics. They are too difficult. Take the blue of the sky, for instance. The blue of the sky occurs to me because of a brilliant Paper by Prof. Strutt, verifying his father's theory of the blue of the sky by some beautiful experiments. It is quite right to give the child some idea of why the sky is blue, but if you make it a systematic part of the teaching you will have to give him Rayleigh's theory about how it happens through the discontinuity of the atoms, and you will lead him into great depths. Or, take a simple thing like the shape of a chain; hang up a rope—a skipping-rope—and ask, What is the shape of that? It is an excellent example for geometry. The properties of the cycloid or the catenary are very interesting, but they are not easy. You may even treat it as an easy problem in the Calculus of Variations, to find out what curve has its centre of gravity lowest; and it comes out the catenary. But all these things are more interesting when you know mathematics than when you don't. Or, take the spinning of a top—a whip-top—a familiar object, but to explain it properly you need Sir George Greenhill or somebody of that kind.

But it may be said, What about the materials which, while quite common, do not obviously involve mathematics, such as those dealt with in the Paper I spoke of, where attention is called, for instance, to the smeariness of butter. You are supposed to take butter in the fingers and feel the smeariness of it, and you might similarly deal with the stickiness cf jam. What I say about those things is that they also are an adult study, in so far as they are a study at all. The child knows these things; takes them for granted: it does not occur to him to treat them scientifically; that would only occur to adults. When you have done a lot of physics and chemistry then you may recognise the science underlying common things. Then you may perceive that viscosity is interesting, and may be able to deal scientifically with many common experiences; but I do not feel that treacle, butter and ordinary things are interesting to the young; or that their powers of observation can well be cultivated upon them.

For cultivating the faculty of observation the biological sciences are surely the best to begin with; and for examples which involve mathematics I should take simple things, artificial things, things which can readily be dealt with, and dealt with graphically. One such thing would be, having drawn an ellipse, to tell the students to find out some things about it to, verify the equality of the angles, for instance—the principles which enter into the making of a mirror. Or, take any other bi-polar curve: Instead of taking the sum of the distances constant to two fixed points, take the difference, or the product, or the ratio, of the distances as constant. Thus, draw two points 3 in. apart, and make a curve every point of which shall be twice as far from one as the other. Well, you get a circle, and if you take different ratios you get a system of co-axial circles; but the boy will not expect that. He will make a drawing, and if he draws it right, you can easily check it; that is one advantage of problems for examination purposes. This kind of problem illustrates to the child the sort of law and order that runs through things. And it is more interesting when he discovers a fact for himself, and does it as an exercise, than when he is merely told about it. He need not be told how to draw a circle through these points, or round a triangle, for instance. Then I dare say something can be done with experiment on a pendulum, the plotting of simple harmonic motions, beats and interferences; and then, again, leaks, the leak of water out of a vessel, or of heat out of a body, or the leak of electricity from a condenser; the theory of leaks—the logarithmic decrement business—gives a good exercise at a higher stage.

Nearly all these things can be dealt with properly by a mathematical teacher. But there are certain problems in statics which seem very dull, and which, I think, can be enlivened by reading old books on mechanics. I came across recently Galileo's "Dialogues on Mechanics"—not the "Dialogues on the Copernican System," but on mechanics—they are translated into English—and the kind of problems treated are quite interesting. Then, there are Thomas Young's "Lectures on Natural Philosophy," which are full of instruction to a teacher. And there are Newton's experiments on the prism, the classical example of accurate experimenting in a new field. But what I feel is that teachers are very apt to overdo the metrical side of physics. It is easy to give people things to measure, but unless they take some interest in the things themselves they do not want to measure them, and the mere learning of how to measure them does not do any particular good. I used to put the students through certain courses of junior study, such as determining the height of a barometer, the time of a pendulum, the moment of a magnet, specific gravity, expansions, specific heat and many other things; they went through these courses—or curses, as they used to be called—but I never felt quite happy about them. It seemed to me that they were rather dull (I was giving them lectures as well, of course, which were more lively). The great bulk of them did not want to measure the things at all, and it was very little use to show them how to measure things of no interest.

And remember how artificial measurement is! An electric current was a fascinating thing in youth to me, but I never thought of expressing it in amperes. Amperes, volts and ohms are quite recent—at least more recent than I am. Things themselves, apart from units of measurement, are interesting; and from the point of view of having a wide scope some acquaintance with a large number of real things is desirable, though how it is to be managed with any precision I do not know.

What I have in my hand are the notes of an article I have recently written, and which will appear in the August "Fortnightly Magazine"—why it is called the "Fortnightly," being a monthly, I cannot say—on Humanistic Science, that is to say, science treated as one of the humanities. I do not say it is easy so to treat it, but I do think we must make the attempt, and realise that for the majority of children science should be treated partly in that way. Literature, for instance, should not be treated simply by rules of syntax and prosody—you could spoil literature by over-attention to syntax, and spoil a poem by treating it as an example of prosody, and we are rather apt to treat science in the same sort of way. I feel that the teaching of science should be exhilarating. Astronomy, for instance, is a very suitable subject—I mean quite elementary observational astronomy—even without any great precision; the students should have their attention drawn to the heavens, and told what can be said about them by those who are competent to tell it. They must be told; they cannot find out things for themselves, and it is our business to pass on our accumulated knowledge to the next generation. They will absorb it fast enough. And if they can go further, and get an idea of law and order, some notion of Kepler's laws in dealing with the planets, and begin to realise gradually the way in which Newton's theory explains and vivifies these laws, turning them from empirical pieces of observation into a unity, like beads threaded on a string, having the thread of law and order running through them all—if the whole course could lead up to a full appreciation of what Newton had done in astronomy—whether it is feasible for the majority of men I do not know—that alone would give a feeling of reverence for science which could not but bear fruit in the future.

*Experimental and Descriptive Physics.** *By* Prof. R. A. Gregory, *Chairman of the British Association Committee on Science Teaching in Secondary Schools.*

When science teaching was introduced into Rugby School about 60 years ago the instruction consisted of lectures and demonstrations. The apparatus used at that time was elaborate and expensive, and it was not adapted for use in experiments by individual pupils. It was the late Prof. A. M. Worthington who first showed that courses of practical work with simple appliances could be carried out successfully in school physical laboratories. His "Physical Laboratory Practice," published in 1886, embodies the experimental course developed by him at Clifton College, and afterwards introduced into many other schools.

The next stage in the teaching of physics in Secondary Schools is represented by the syllabus of Physics and Chemistry put forward in 1895 by a Committee of the Incorporated Association of Headmasters. In this syllabus measurement was insisted upon at the outset as the chief factor in scientific work and as the basis of scientific reasoning. It was urged that a large proportion of time given to science in schools should be occupied by the pupils in performing actual experiments themselves, and that the object should be to impart, not merely information, but chiefly the knowledge of method, and, with this object in view, that the instruction should be given in strictly logical order. The course was intended to be truly educational, and not for the preliminary training of chemists or physicists alone; it was devised to provide clear ideas of scientific method and reasoning rather than to cover a wide range of information, such as may be gained from text-books or other descriptive literature.

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* Communicated before the meeting.

The adoption of the principles of this syllabus by the Oxford and Cambridge Local Examining authorities, and by other bodies concerned with school examinations, has determined the character of school instruction in physics during the last 20 years. Questions have been set which demand personal acquaintance with experimental work and results rather than knowledge gained by reading or from lectures, with the consequence that most of the time available for science teaching has been taken up with laboratory exercises, and descriptive lessons have occupied a secondary place in the course. As precise laboratory work requires much more time for its profitable performance than is needed by didactic instruction, the actual ground covered must be less, even though the mental training is infinitely better. So it has come about that the majority of pupils in our Secondary Schools never get beyond the stage of determining specific and latent heats in their course of physics, and they leave school knowing nothing of the principles of such everyday instruments and appliances as field glasses, electric bells, telephones, periscopes, spectroscopes, dynamos, motors, incandescent and arc lamps, fuses, and many other applications of physical science met with in everyday life.

This condition of things has for some time been felt to be unsatisfactory, and much attention is devoted to it in the Report of Sir J. J. Thomson's Committee on The Position of Natural Science in the Educational System of Great Britain. It is pointed out that a general course in science, suitable for all pupils, should fulfil two functions—namely: (*a*) it should train the mind of the student to reason about things he has observed for himself, and develop his powers of weighing and interpreting evidence; (*b*) it should make him acquainted with the broad outlines of great scientific principles, with the way in which these principles are exemplified in familiar phenomena, and with their applications to the service of man. In recent years the first of these functions has been over-emphasised and the second neglected. The teaching of physics has become almost entirely quantitative, and little has been done to create and foster interest in the broad field in which every intelligent mind can find pleasure. It is important to provide training in scientific method, but it is even more important that every pupil should be given a sense of the wonder and value of scientific achievement. All science is not measurement and all measurement is not educational, nor does it appeal to all pupils, whereas few are incapable of appreciating the intellectual and industrial value of discoveries in the realm of physical science.

It ought to be recognised that much of the instruction in elementary practical measurements of length, area, volume, mass and density should be given by the mathematical staff, and not by the science staff.

This was recommended by a joint committee of the Mathematical Association and the Association of Public School Science Masters in 1910. Such work can be done in an ordinary classroom with the simplest apparatus, and is thus more easily co-ordinated with the mathematical lessons than when carried on in a room specially devoted to it. The course of measurements, including the use of simple balances, need very seldom exceed 20 hours of practical work; and there can be no doubt that it is of the highest value in giving actuality to the mathematical teaching. Unfortunately, mathematical teachers have usually little sympathy with these practical methods of instruction, so that the fundamental measurements which give reality to their formulæ and operations have to be done in the two or three hours a week devoted to science. If teachers of physics were relieved of this preliminary work, it would be possible to cover much more ground than can be touched under existing conditions.

Both Sir J. J. Thomson's Committee and the British Association Committee on Science Teaching in Secondary Schools, which issued its report last year, urge the necessity of directing more attention to those aspects of science which bear directly on the objects and experience of everyday life.

At present, as instruction in science proceeds in the school, there is a tendency for it to become detached from the facts and affairs of life, by which alone stimulus and interest can be secured. It is important that every opportunity should be taken to counteract this tendency by descriptive lessons in which everyday phenomena are explained and the utility of discovery and invention is illustrated.

The summary of the section of the British Association report dealing with principles and methods of science teaching states the main points to be borne in mind, whether in the teaching of physics or any other branch of science. It is as follows:—

"The observational work by which the study of science should begin opens the eyes of the pupils, and may be used to train them in the correct expression of thought and accurate description. The practical measurements in the classroom have for their object the fixing of ideas met with in the mathematical teaching. Every pupil should undergo a course of training in experimental scientific inquiry as a part of his general education up to a certain stage, after which the laboratory work may become specialised and be used to supply facts which may be a basis for more advanced work or to prepare pupils for scientific or industrial careers.

"At suitable stages, when pupils are capable of taking intelligent interest in the knowledge presented, there should be courses of descriptive lessons and reading broad enough to appeal to all minds and to give a general view of natural facts and principles not limited to the range of any laboratory course or detailed lecture instruction, and differing from them by being extensive instead of intensive.

"Finally, the aims of the teaching of science may be stated to be (1) to train the powers of accurate observation of natural facts and phenomena and of clear description of what is observed; (2) to impart a knowledge of the method of experimental inquiry which distinguishes modern science from the philosophy of earlier times, and by which advance is secured; (3) to provide a broad basis of fact as to man's environment and his relation to it; (4) to give an acquaintance with scientific words and ideas now common in progressive life and thought."

The most urgent need at the present time is to devise suitable courses in which these principles are followed, so that all pupils may be given a broad view of the results of scientific work, as well as be introduced to experimental methods of inquiry. Under existing conditions, which are largely controlled by prescribed syllabuses and external examinations, there is little opportunity for teachers to direct attention to the useful applications of science on one hand, or on the other to awaken interest in inspiring principles. If, however, an authoritative body like the Physical Society can produce a practicable scheme of work suitable for all pupils up to about 16½ years of age—that is, to the stage of the First School Certificate—and will secure the adoption of the scheme by the examining bodies which will award this certificate, a valuable service will be rendered to teachers and to education.

Prof. **Gregory** said: It is many years ago since I was actually engaged in the teaching of physics, and in those days it was true of me—what naturally would be true of a teacher of physics, or a teacher of any other subject—that my interests were largely concentrated upon my own particular branch of science. Well, for a quarter of a century now I have been actively associated with science in a periodical form—in "Nature"—and this has enlarged my views and taken me outside the interests alone of the physical laboratory, or of physics as usually understood, opening up a larger field than was at all possible when I was engaged in teaching one branch of science only. It is, therefore, with a certain amount of diffidence that I appear this afternoon before teachers to express any opinion upon the teaching of physics; indeed, I do not propose to trespass upon their field by giving expression to any decided opinions of my own as to details in connection with the teaching of physics; but I may be permitted to refer to one or two views which are now becoming general as to the importance of science teaching as a whole and of physics in particular.

In all subjects one really recognises three stages of development. There is, first of all, the stage when the advocate and the reformer come forward with views as to the necessity or the advisability of introducing what may be a new science, or a new spiritual doctrine, or a new system of ethics. At any rate, you have that definite stage of the fervid reformer who proposes to rejuvenate the world with his new teaching. That is the most active stage, and in the case of physics the science passed through it about 60 years ago, in the time of Kingsley and Huxley and Tyndall, and the carrying through of the first course of physical science teaching at Rugby School. The next stage is when teachers begin to reduce the work to formulæ, to produce a logical course, a plan of teaching; in a word, to create a system out of those views which had been advocated and put forward in an ungeneralised form. You have the same thing in the case of a new gospel. After the early stages of its apostles, you developed a formula and a liturgy. Next you reach the third stage when you begin to inquire into the foundations of your belief and teaching. These three stages are definitely represented in physics. In my early days, as a student, physics was made very interesting The experiments were qualitative, but they covered a wide field. As a boy I was introduced to fundamental measurements, heat, light and electricity, very superficially it is true; but one did see how wonderful these things were—quite as wonderful to many minds as the world of natural history, to which Sir Oliver Lodge has referred. About 20 years ago the Association of Headmasters produced a scheme of work in which the dominant principle was quantitative measurement and discovery by the pupil at all stages. The main part of the teaching was to be quantitative instead of qualitative. That scheme was after a time adopted by the University Locals authorities, and, as those who are concerned with secondary schools know, this meant that it became the usual course in secondary schools—at any rate, in schools of the State-aided type. You had the stage of precision, a definite course being given, and the pupil being expected to follow on from one point to another. Well, the result is, as those of you who are familiar with State-aided secondary schools know, that the majority of the pupils leave these schools, never having got beyond the determination of specific heat and latent heat. They could not mend an electric bell or adjust a fuse; they know nothing of the common things around them—apparatus and instruments; they never get near them, because precise measurements occupy all their time.

Well, we have had the same kind of thing in the teaching of other subjects. Algebra passed through the same stages. In my early days we were never expected or given the opportunity of using a table of logarithms until we had passed the theory of indices. In the case of geometry, we studied practical construction as a thing apart from the ordinary course of theoretical studies. Modern languages have been through much the same stages of development. From the grammatical stage we passed to the direct method of teaching languages, and now modern language masters are beginning to consider whether there should be a combination of the direct and the grammatical method, or which is the better of the two. We have these stages in the teaching and growth of most subjects. I am reminded of an essay written by a boy on the three ages of man. "The first age of man is when you are young and think of all the wicked things you are going to do when you grow up; that is the age of innocence. The next age is when you have grown up and done all the wicked things you thought about; that is the prime of life. The third age is when you are old and repentant, and that is dotage." Well, I think we have perhaps arrived in the third stage—at least in my own case—for I have been responsible for a fair number of books in connection with the teaching of physics in which the logical method had to be followed. I am repentant in a way, because I am very much in favour of what Sir Oliver Lodge has said—I have spoken and written on that point many times—with regard to the distinction between the training of the boy who is going to become a serious student of physics at the University perhaps, and is entering engineering or industrial work later, and the place of physics in the general education of those who are not taking up the subject in connection with a career. There can be no question that if you are given boys and girls up to the age of about 16 years, when one may suppose that the general education will terminate, the present course of physics as followed in State-aided secondary schools, devoting a year or more to fundamental measurements and a year or more to heat, and reaching optics and electromagnetism towards the end, perhaps, is most unsatisfactory. The difficulty comes in when arranging a course which will satisfy both your aims. I think it can only be solved by associating with your laboratory course—which is essential in order to get an appreciation of scientific method—descriptive lessons, which must not be limited to or follow the work done in the laboratory, but be independent. Usually, as teachers here very well know, the demands of examining authorities are such that it is necessary to adapt the descriptive lessons closely to what is done in the laboratory. The questions that are set demand intimate acquaintance with laboratory details, and it is necessary to elaborate these in the lessons upon physics connected with the course. Now I should like to see particularly a course that was of a descriptive and inspiring kind, such as that to which Sir Oliver Lodge referred, and it is for teachers to consider, in association with such a Society as this, whether it is not possible to produce such a combination suitable for the instruction of every boy or girl attending a secondary school. The ignorance of common apparatus and common phenomena now exhibited by the man in the street—I will not say anything about the woman in the street—is such that I am sure it ought to be deplored by a progressive nation. A friend of mine told me that a few days ago, in a very important camp, the colonel placed an ordinary recording barometer in the messroom. An officer came in and looked at the instrument, and after examining it for a time he said: "I don't see what good this thing is. It only shows 30, and this room's as hot as blazes!" He would have benefited by a little introduction to a descriptive course of physics in schools. Another officer, a little more familiar with the subject, looked at it and asked its object. "Yes," he said, "that is all very well; but what is the good of a barometer which doesn't show dry or rainy or fair weather?" Apparently he thought a barometer of no use at all unless it was one of the sort which you can tap and watch the pointer move. That is the kind of thing we have in consequence of the neglect of the general study of science in our schools. The general body of pupils is neglected in comparison with the small proportion of pupils who are specialising in the subject. All I wish to plead for this afternoon—all that is embodied in my remarks on this matter—is that we should try to produce some combination of descriptive teaching with the laboratory course, to appeal particularly to the general student, instead of to the specialist only.

The Place of Physics in the General Education of Boys up to the Age of Sixteen.

Mr. C. L. **Bryant**, M.A., of Harrow School, said: Mr. President, ladies and gentlemen, I think it will be wise of me to confine my remarks almost entirely to the public schools, for about them my knowledge is most certain. During the past four years, as one of the Secretaries of the Association of Public School Science Masters, I have had occasion to learn fairly intimately the conditions prevailing in the public schools. Also I shall restrict myself to speaking of the place of physics in public school education.

There is quite an extraordinary unanimity of opinion among teachers that boys ought not to specialise before the age of sixteen. The First School Examinations now are meant to test this general education. What can be done between the ages of sixteen and eighteen (when many boys pass on to the universities) in the matter of limiting specialisation for those who wish to continue the study of science, is a different problem altogether. The schoolmaster who thinks at all—and most of us do, in spite of the prevalent opinion to the contrary—is always asking himself why he should teach the subject on which he is chiefly employed; and the aim of the science master—I hope I may be forgiven the statement—is not so much to teach science as to produce good men of sound judgment. The kind of judgment fostered by scientific training has this against it, that it must almost certainly be slow. The judgment of any special case of science requires special consideration from all the circumstances affecting it, and the process takes time. The same kind of judgment is required in a player of football, but in his case a very short time limit is imposed. But the great importance of science in education lies in the field in which evidence must be sought. It is not in tradition or in history or in any written book of the past that the seeker must look, but in the open book of Nature, of which, so to speak, there is a daily publication. And then, of course, there is the obvious utility of the subject matter. In order to describe our general aims, I cannot do better than quote from a memorandum drawn up by the Association to which reference has been made. This memorandum dates from October, 1916, and refers to the place of science in general education. It states that the first aim of science is the search for truth, and it goes on to say that its subsequent establishment depends upon accurate observation with constant recourse to Nature for confirmation. The one aim of natural science is, in effect, the search for truth based on evidence rather than on authority. Honest study of the subject implies accurate observation and description, and fosters a love of truth. The special value of natural science in the training of the mind and character lies in the fact that the history of the subject is a plain record of the search for truth for its own sake. Secondly, with regard to utility, there are certain facts and ideas in the world of natural science with which it is essential that every educated man should be familiar. A knowledge of these facts assists men (*a*) to understand how the forces of Nature may be employed for the benefit of mankind, (*b*) to appreciate the consequence of cause and effect in governing their own lives, (*c*) to see things as they really are, and not to distort them into what they wish them to be.

Following that definition of aims, there was drawn up a scheme entitled "Science for All,"* designed to indicate the kind of science teaching suitable in the general education of all boys. This has the universally expressed approval of the Association. It ranges over a wide field, from the universe to the electron. In it a deliberate effort has been made to wander from one main road of science to another. Thus, sound and the physiology of the ear; light and that of the eye; biology and the work of Darwin and Pasteur; discovery and the lives of the discoverers; and—in my own application of it—creation and the

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* Copies of this may be obtained at 6*d.* each from Mr. C. L. Bryant "Ludlow," Harrow.

Creator are not divorced. So it seems against the spirit of the thing to pick out the parts which relate to physics, though I have done so as this is the subject in which you are most interested. But first let me give you the main outline of the scheme.

(1) *Main Headings.*—The Universe. Solar System. Earth. Igneous and Sedimentary Rocks. Volcanoes. Glaciers. Fossils. Coal.

Atmosphere. Life of a plant. Fermentation. Pasteur. Animal Kingdom. Balance of Nature. Darwin. Simple Agriculture. Simple physiology and hygiene.

Natural resources of the Empire.

Mass. Weight. Density. Falling bodies (Galileo and Aristotle). Force and Work. Liquid and gaseous pressure. Diffusion. Capillarity and surface tension. Applications of the above.

Study of Atmosphere. Combustion. Respiration. Water. Limestone, sandstone, clay. Conservation of Mass. Laws of Combination introducing Chemical Theory. Flame. Hydro-carbons. Coal-gas. Nitrogen, sulphur, chlorine and their simple compounds. Acids, bases and salts. Properties and extraction of metals. Alloys. Iron and steel. Petroleum. Coal-tar products. Oils, fats, soap, glycerine. Sugar.

Sources, effects and transference of Heat. Thermometers. Investigation of Heat quantity. Heat and temperature; thermometric scales. Calorimetry. Change of state; vapour pressure. Heat values of fuels. Heat and Work. Horse-power. Mechanical equivalent. Engines.

Rectilinear propagation of Light. Photometry. Reflection and refraction. Mirrors and lenses. The eye. Telescopes and Microscopes. Dispersion.

Wave motion. The ear Pitch, loudness, quality. The gramophone.

Magnets. Lines of force. Terrestrial Magnetism. Cells. Electromagnets. Telegraphs. Conductors and Insulators. Electroscope. Potential, E.M.F. Effects of current. Resistance. Ohm's Law. Current Induction. Microphone and Telephone. Dynamo and Motor. Electrical energy. Lamps. Heat and Work. Units.

Now follow details of the physics included in the scheme. These are very similar to the details of the physics which have been taught up to the present in a great number of schools. If one likes, one can subdivide them into heat, light, sound, and magnetism and electricity. But if you look at the text for some of the details you will see how in almost every case there must be some reason in the everyday experience of the pupil for treating of the subject.

(2) *Details of the Physics Included in the Scheme.*

MECHANICS AND HYDROSTATICS.

Falling Bodies. Galileo's disproof of Aristotle. Acceleration Conservation of Mass and Momentum. Energy.

Based on a machine; in the same way other courses can be based on other machines, *e.g.*, internal-combustion engine, etc.

Hydraulic press. Transmission of pressure: fluids: Solids. Force. Spring balance. Pressure and Tension. Weight. Mass. Work. Pulleys.

Hydraulic Machinery (Lifts, Jacks, etc.).

Pressure and depths in liquids. Lock gates. Density. Specific Gravity (by direct weighing).

Air pressure. Vacuum Brakes. Barometers. Density of Air. Height of Atmosphere. Distinction between Gases and Liquids (briefly). Boyle's Law. Aneroids. Barometer movements and weather.

Diffusion of Liquids and Gases.

Flotation (Ships and Balloons). Hydrometers.

Lactometers. Density of Sea-water. Deep-sea sounding apparatus. Divers. Archimedes' Principle and applications.

Pumps. Lift pump and force pump. Syphons. Air pump. Water-wheels (overshot and undershot). Pelton Wheel. Steam Pressure. Force on piston of steam engine. Simple manometer. Pressure Gauges. Turbines (impact and reaction). Water-rams. Capillarity. Wetting.

HEAT.

A. Heat quantity as experimental investigation.

B. Effects of heat on the sizes of solids, liquids and gases (qualitatively). Sources of heat. Conduction of heat. Davy lamp. Convection of heat. Ventilation and heating of houses. Thermostats Winds. Ocean currents. Water-tube boilers. Radiation (briefly) Expansion of solids on heating. Annealing. Rupert's drops. Unequal expansion of different metals; platinum and glass. Pendulum Control of clocks and watches.

The fixed points of the thermometer. Temperature scales. Air-thermometer. Absolute zero. Clinical, maximum and minimum thermometers. Effects of salt and pressure on melting-point. Freezing mixture. Regelation. Effect of salt and pressure on boiling point. Marcet boiler.

Temperature and heat. Units of heat. Specific and latent heat.

Change of state. Evaporation. Condensation. Distillation (whiskey, petrol). Cold on evaporation (sparklets). Heat on compression (air compressors, Diesel engine, refrigerators). Vapour pressure. Rain. Dew. Hoar-frost. Snow. Hail. Relative humidity. Wet and dry bulb thermometer.

Change of volume on melting. Bursting of pipes. Freezing of ponds. Change of volume on boiling; hence steam pressure.

Radiation. Characteristics. Cold nights with cloudless sky. Thermos flask. Glass fire-screens. Hot-houses.

Heat values of fuels. Heat and work. Forms of energy. Work and power. Horse-power. B.H.P. of an engine. Mechanical equivalent. Conservation of energy. Steam engine (general outline). Energy losses. Work done by expanding steam in cylinder. I.H.P. Efficiency.

LIGHT.

Rectilinear propagation of light. Candle-power. Intensity of illumination. Photometers. Plane mirrors Laws of reflection. Searchlights. Images in spherical mirrors (geomet. construction ; no formulæ) Refraction. Index of Refraction. Apparent depth of pond. Internal reflection.

Prisms. Lenses. The eye. Accommodation. Defects of vision. Spectacles. Magnifying glass. Astronomical telescope. Terrestrial telescope. Magnifying power. Field of view. Microscope.

Dispersion. Colour. Rainbow.

SOUND.

Nature of waves on water surface. Frequency. Wave-length. Nature of sound waves in air. The ear. Vocal cords. Pitch due to frequency. Doppler effect. Siren. Velocity of sound in air. Wavelengths. Gramophone. Claxon horn.

MAGNETISM AND ELECTRICITY.

Magnets. Magnetic fields. Polarity. Earth's Magnetism. Compass needle. Cells and batteries. Electromagnet. Telegraphs. Conductors and insulators.

Electrification. Electroscope. Potential. Capacity. Condensers. E.M.F. of cell shown on electroscope.

Effects of current ; heating, chemical and magnetic. Measurement of current by any of these effects. B.O.T. unit of current. Current capacity of wires. Ammeters. Resistance. Ohm's Law. Voltmeters. B.O.T. unit.

Current induction. Microphone. Telephone.

E.M.F. in wire moved across magnetic field. Dynamo. Magneto. Alternating current. Commutator. Motor.

Self-induction. Induction coil. X-rays. Wireless telegraphy.

Electrical energy. Heat. Electrical power. Watt. B.O.T. unit of energy.

Lamps. Parallel circuits Wiring of houses.

Now for one or two explanatory remarks on it. This is meant to be taught to all boys between the ages of fourteen and sixteen, and the majority of them will not be interested specially in science later on in life. The courses are therefore designed to be self-contained, and are not formed so as to lead on to the more specialised study of science. Why should the grammar of science, and that only, be imposed on all ? The drudgery of learning the elements of heat, of chemistry, and so on, is exactly comparable with the study of the Latin Primer, which is of small value except to those who are to make a special study of the Classics. This desire for the exact knowledge of detail is characteristic of adults, and, even so, is only indulged when there is reason for its satisfaction. How many of us would care to learn the Russian alphabet unless we had reason to know that we should be able to utilise our knowledge of the language ? And why impose such tasks on the defenceless boy ? The boy does not wish at first to learn about abstract principles of science. Again, speaking from my own experience, as I got on in years I did find the fascination of probing a subject to its very depths ; but that was not in my boyhood's time, and, unless I mis understood Sir Oliver Lodge just now, it seemed to me that his experience is different from mine. It is a serious matter to differ from Sir Oliver Lodge on any point of science or education, and especially on a point which combines the two, but in my judgment, and from my own experience, I should say that boys learn very quickly from the concrete, whereas older people are more willing to learn from elementary principles. I remember some years ago an academic discussion on the value of following out the line of historical discovery in science in teaching any special subject, and there were some who thought that one ought to take principle after principle as it was discovered, and so work up to the common ground of knowledge of the present day; others held the contrary view. But I recollect a remark by the Headmaster of Oundle, who said that he believed in the historical treatment of the subject, but that history ought to be read backwards!

Imagination comes before discovery in natural science; the vision comes before the detailed work. It is this vision and the incentive to work that we wish to give the boys first of all. Too many people credit boys with the desire for learning for its own sake. That is about equally rare among boys and among grown up people. Each beginner in science should learn something of man's place in the universe.

To my mind, the most glaring fault of the science teaching of public schools at the present day is the neglect of mechanics, a subject most important for the study of nearly all branches of science.

To pass from our aims and ideals to the conditions under which we work, examinations hamper us far too often. Examiners are often without experience of the teaching in the schools. They seem unable to break away from the antiquated rudiments of chemistry, heat and optics. No teaching is more hampered from these circumstances than is science. The subject matter of the scheme I have outlined is admittedly difficult to examine in, and there must be more co-operation between examiner and teacher. Again, I strongly oppose the grouping of science with mathematics in the First School Examination. Training in science is at least as important as the study of language, which has a group to itself; and there are other reasons of school politics which make the grouping undesirable.

Boys should be graded for science separately from literary subjects A boy should not go up through various science divisions of a school according to the form he happens to be in, if the placing of the form depends chiefly upon literary subjects.

The system of scholarships on entrance to public schools has the result that the boys, having begun to specialise in Classics, naturally stick to the subjects they have found to "pay." Boys come from the preparatory schools to the public schools rather below the age of fourteen and leave at the age of eighteen or nineteen. In the majority of State aided secondary schools, on the other hand, training is continuous from ten to seventeen. In the preparatory schools it is rare to find science taught at all. This is not altogether the fault of the preparatory school masters, for they teach what the public schools require in the matter of entrance examinations; but the result is that the sons of the wealthy begin their training in science about four years later than their less fortunate fellows! Even in these days there are public schools where boys—usually the most able—can pass through without having had any training at all in science. We do insist that the boys should be regularly instructed in preparatory schools in Nature study and Practical Measurements. By the former, habits of observation and description can be cultivated, while the latter form the basis of all work in physics.

Physics for Older Boys.

Dr. T. J. **Baker**, King Edward's High School, Birmingham, said that the honorary secretary had very kindly asked him to offer some remarks on a part of the subject which was obviously closely related to that dealt with by Mr. Bryant. The course of science work through which the boy had passed before he reached the age of 16 years might influence the rate of his subsequent progress very considerably. The boy who had assimilated the "Science for All" course should be in a favourable position to profit from the more exact treatment which became necessary when he began to specialise. The question whether boys should leave school between the ages of 16 and 17 in order to enter directly upon the more specialised science work at a university could have only one answer from teachers who had had experience in schools. A boy of 16 or 17 must possess most unusual qualities of concentration and determination if he was to profit from the instruction offered him. The discipline of the school kept the boy definitely at work for prescribed periods; at school he could not "cut" the lesson. But at the university he was a freer agent, and, within limits, he might or might not do the work. Boys of that age had not sufficient stability to be trusted to work steadily under such conditions. Quite apart from this consideration, it should be borne in mind that a university was not making the best use of its powers when it undertook science teaching which could be carried out efficiently by the schools. One had heard of professors who had stated that they preferred their students to come to them with no knowledge of their particular subject rather than that they should have started it at school. But the experience of such professors must have been particularly unfortunate. Sir Clifford Allbutt, the Regius Professor of Physic at Cambridge, said in 1915, with regard to the fairly recent regulation which allowed boys to take part of the first M.B. direct from school, that the results had improved largely on those obtained in the past. The men coming forward were not merely as good as in the past, but were far better. The assumption had been made frequently in discussions that 16 years represented the age at which boys had reached the standard of general education corresponding to matriculation. Statistics showed that the number was greater for matriculation at 17 than at any other age. The speaker had found from the records of the past 10 years in his own school that the average age of the boys who had matriculated was about 17 years and two months at the time when they began their specialised course in science. This seemed to be in fairly close agreement with the London University statistics, and showed that it was unsafe to assume that post-matriculation work began on the average at 16 years. The report of Sir J. J. Thomson's Committee recommended a lowering of the age for open scholarships at the older universities from 19 to 18, and that an appreciable fraction of the school time of prospective candidates should be devoted to literary work. Under such an arrangement the university course in science would of necessity start from a lower level than at present. It must be remembered that, after all, only a certain small percentage of boys were likely to proceed to the older universities, and therefore it was desirable to consider how the others would be affected by a scheme which insisted upon a less specialised post matriculation science course.

The boy who left school immediately after matriculating and proceeded to one of the newer universities would start at once on a completely specialised course in medicine, engineering or pure science. He would not be required to work at any literary subjects. If he remained at school the new scheme would insist upon part of his time being given to literary work. Parents would be likely to consider such time as wasted, and boys would be removed from school when they had matriculated, and would be sent to the university at once. There they would be doing the work, and that work only, which would lead to a degree. It was open to grave doubt whether the newer universities would alter their first year courses to bring them into line with the post-matriculation courses proposed for schools, and nothing short of this would be effective in preventing boys from evading the proposed less specialised post-matriculation courses in schools, and thus missing the advantages which such courses offered from the point of view of general education.

The Board of Education, in proposing the institution of two examinations in grant-earning schools, plainly recognised that many boys would be more than 16 years of age by the time they were ready for the first examination. The second examination was designed for those who had continued their studies for two years after the stage of the first examination. The secretary had told him (the speaker) that it would be useful to state his views on the maximum in physics which could be expected from boys of 18 who had been specialising for two years in science, and he was in some difficulty in this respect, because in his experience very few boys had been specialising in science for two years at the age of 18; indeed, most of them would have been specialising for not much more than one school year. Among 12 boys who were taking the Intermediate Science and the first Medical Examination, the average age was 17 years and seven months (a younger group than had been usual for some years), and eight of these boys had been specialising for one school year only. Taking these circumstances into consideration, it appeared that the standard of work required by an Intermediate Examination in Science represented something like the maximum which might be expected at an age approximating to 18 years. It was also necessary to remember that the majority of these boys would not be candidates for open scholarships at Oxford or Cambridge, and that an estimate of what might be expected from them should not be based upon the performances of the few who were likely to be successful in such competitions. He thought that in some of the post-matriculation syllabuses brought forward there were certain requirements which might with advantage be left to a later stage, such as shear strain, viscosity, surface tension, Carnot's principle and its applications, fourth power law, diffraction and polarisation of light; although these might be dealt with successfully in the second year when the boys would probably be rather over 18 years of age. The difficulty of dealing with these boys was often increased by their imperfect knowledge of the principles of mechanics. In a fair number of cases they had taken the subject for matriculation, but it frequently happened that one came across boys who had never studied it at all seriously before entering upon the Intermediate Science course. This arose from the circumstance that the parent often postponed his decision as to his son's future career until he had matriculated. Referring to a two years' post-matriculation syllabus put forward by one school, he said that in his opinion it was altogether too ambitious, for it aimed at preparing boys of 18 for a B.Sc. examination with honours. The schemes proposed by two other schools corresponded fairly closely with the usual requirements of an Intermediate Examination in science. The speaker distributed among those present cyclostyled copies of a syllabus of physics for boys of 18, which dealt with the phases of the subject treated under the headings of heat, light, sound, magnetism and electricity, and included some suggestions relating to the additional work which might be required from boys of about 18 years and six months, who had given nearly two years to the subject. He concluded by saying that he had no wish to dogmatise with regard to exactly what should and what should not be done, but he put forward this syllabus as a suggestion.

Syllabus of Physics for Boys of 18.

HEAT —Temperature. Expansion and consequences. Quantity of heat. Specific heat. Conduction. Change of state. Latent heat. Vapour pressure. Hygrometry. Mechanical equivalent of heat. Elementary radiation.

LIGHT.—Rectilinear propagation and consequences. Photometry. Reflection at plane and spherical surfaces. Refraction and dispersion. Prisms. Use of spectrometer. Lenses. Simple optical instruments. Defects of vision. The spectrum. Colour, Velocity of light.

SOUND.—Nature of waves. Loudness, pitch, quality. Velocity of sound in air and other media. Vibration of wires, transverse and longitudinal. Determination of frequency. Resonance. Vibration of air in pipes. Beats. Doppler's principle.

MAGNETISM.—Induction. Inverse square law and consequences. Magnetic field Pole strength. Moment of a magnet. Magnetisation of iron Earth magnetism.

ELECTRICITY.—Simple electrostatics. Charge. Potential. Capacity. Energy of charge. Specific inductive capacity. Cells. Accumulator. Properties of the current. Measurement of current. Force on current circuits in magnetic field. E.M.F. Resistance. Ohm's Law and consequences. Ampere, volt, ohm. Heat production in circuits. Joule's Law. Electric energy. Electric power. Electrolysis and electro-chemical equivalents. Electromagnetic induction. Transformer. Induction coil. Principle of dynamo and motor. Thermo-couple and its uses. Microphone. Telephone. Potentiometer.

Additions for Boys of about 18 years 6 months who have given nearly Two Years to the Subject.

General Physics.—Motion in a circle. S.H.M. Simple treatment of moment of inertia. Compound pendulum. Density of earth. Young's modulus. Simple experiments on torsion. Surface tension. Deviations from Boyle's Law.

Heat.—Enough elementary thermodynamics to give ideas about adiabatic processes and efficiency of heat engines. Indicator diagram. Radiation.

Light—Simple application of wave theory to reflection, refraction, interference and diffraction. Simple polarisation. Application of Doppler's principle. Colour.

Magnetism and Electricity.—Permeability. Susceptibility. Intensity. B. Calculation of field in simple cases. Inductance. Ideas about electric oscillations leading to wireless telegraphy. Discharge of electricity through gases

The President said that Mr. Sanderson, the headmaster of Oundle School, who was to have taken part in the discussion, had sent a telegram regretting his inability to be present. He (Mr. Sanderson) had added that he would like to see a small committee formed to report on science work in schools of different types and to consider science work in advanced courses and continuation courses. The President added that Mr. Sanderson had lost his son in one of the recent advances, and that he had our sincere sympathy. He thought Mr. Sanderson occupied a prominent place amongst those who believed it was best to teach boys by going from the concrete back to principles; or, to use the illustration which had been brought forward in the course of the discussion, to argue back from the steam engine to Boyle's Law. Or, as Mr. Bryant had expressed it, he believed in teaching history backwards.

*The Teaching of Physics at Osborne and Dartmouth.** *By* C. E. Ashford, *M.V.O., Headmaster of the Royal Naval College, Dartmouth.*

Osborne takes in the same material as the Public Schools. There is no competitive intellectual test at entry. But the final aims differ to some extent: Public Schools aim at developing a typical character, but foster all possible varieties of mind; while the executive branch of the Navy should contain men who conform to one fundamental type of mind as well as of character. It may be assumed that any one officer will carry out the same duties as any other at some time in his career, though not in the same order, the chief exception being that the abler half will also specialise for 10 or 15 years. So the education must be framed with regard to these typical qualities. For example, Cadets should develop into men of action rather than students, ready to continue indefinitely to learn for themselves by observation and experiment rather than from teachers or books. They must be many sided, keen on everything, from machinery to strategy; they must possess or cultivate the power to make instant decisions, and an aptitude for improvising means to meet novel conditions; they must have their knowledge at call, and not merely know where it is to be found; they must face facts and abhor prejudices. Such an analysis suggests that experimental science should be an admirable discipline for them.

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* Communicated before the meeting.

Cadets enter Osborne at 13–8, and normally end their general education on leaving Dartmouth about 17. After this they take a technical course of eight months in special cruisers, and then go to sea as officers. The course in Physics begins with an unsystematic treatment of Hydrostatics, to introduce Cadets to an orderly habit of thought, observation and description. They also begin at once in the Laboratories and Engineering Workshops.

The effect of the rapid alternation of theory and actual practice throughout the course is found to be extremely favourable to both, not least in the case of young boys. Workshop practice makes demands on the recently acquired store of scientific knowledge in a fashion well suited to the budding Naval Officer, who will have to think while standing up and doing a job; a limited amount of knowledge ready at his finger tips will be of more service to him than a much wider amount available only in a special environment. And the habit of learning from what he is actually doing will stand him in good stead in carrying on his own education. Conversely, the concrete experience of the shops stimulates his interest in theoretical work, and supplies the teacher with endless illustrations.

During following terms the subjects taken are Statics, Heat, Magnetism and Direct-current Electricity, Kinetics and Hydrostatics. The time devoted to them is roughly three or four hours a week in lectures, one hour for preparation and two in the laboratory. The average Cadet does not, as a matter of fact, get as broad or as full a knowledge of pure Physics as a boy who has passed up the modern side of a good public school—*e.g.*, Geometrical and Physical Optics and Acoustics are not touched—and there is more Applied than Pure Physics in those subjects that are dealt with. But in a public school the weaker boy never reaches the upper levels, while practically every Cadet who enters Osborne takes the Passing Out Examination, and is put through the full course; this produces considerable difficulties in organisation, but that is perhaps a smaller evil than persisting in a course for all which is adapted only to a few, and letting the remainder leave it uncompleted. The practical nature of this compound of pure and applied Physics with Engineering seems to appeal better to the average boyish intelligence than does pure Physics alone, and there are fewer weaklings than might have been expected. The abler Cadets of each batch are given work that is more difficult and more generalised and abstract, as a foundation for the specialist courses which they will take later, and various methods are adopted to stimulate them to exert their full powers.

Many problems have presented themselves; one is the question of text-books. There is a strong temptation, especially where much ground has to be covered in a short time, to give full lecture notes or a text-book written for the prescribed course. These give no practice in extracting items of knowledge from a mass of irrelevant material; it became clear that we must sacrifice speed of progress for ultimate gain, and it was found that the early retardation was almost balanced by more rapid progress at the end even of this short course.

The relation of Mechanics to Physics is another difficulty. In many Public Schools this is treated as a branch of Mathematics; it comes late in that course, and many science masters have made a successful effort to teach the earlier stages of Physics without depending on it. There is much to be said for this procedure, if only because comprehension of mechanical principles seems to be a function of age, and the commencement of Physics cannot wait for the attainment of that age and the subsequent courses in Mechanics. At Osborne and Dartmouth Cadets are concerned from the first in their engineering with mechanical ideas and principles, so that to obtain co-ordination it is necessary to start serious work in Statics as part of the Science course earlier than would seem advisable on other grounds, and to introduce Kinetics as soon as Cadets are at all ready for it. Experience seems to show that these young boys can learn the mechanics required, but with considerable difficulty and much more slowly than if they were older. The method of teaching must be adapted to their special needs; but probably such a change would be good even for older boys with a better mathematical equipment who are liable to trust to their power of dealing with symbols and avoid the trouble of thinking mechanically. The system adopted is not to start with metaphysics and abstractions, but first to take four or five machines (*e.g.*, screw-jack, Weston block, &c.), and examine fully in the laboratory their behaviour, measuring and plotting their velocity ratio, efficiency, &c., under various conditions. Moments arise naturally, and their forces are treated (in the class-room) as vectors, with the ordinary logical development of statics. At the age of about 16, kinetics can profitably be dealt with; it is treated experimentally so far as possible, with kinematics only as it arises and mathematical formulæ postponed; prominence is given to momentum, work and energy, and problems solved by their use whenever convenient.

Several methods of teaching the earlier stages of Electricity have been tried; that which has proved most satisfactory is a term's work of a qualitative and unsystematic kind, dealing with the behaviour of such things as electric bells, dynamos, motors, induction coils, primary cells, resistance coils, etc. Then follows the electrolytic measurement of current; next the electrostatic voltmeter, using voltaic and not frictional electricity. With the ability to measure Current and P.D., Ohm's Law can be verified, and the conception of Resistance deduced. It has been found that this process results in an absence of the confusion between Current and P.D. which is common among beginners.

It may be worth adding that Osborne and Dartmouth must, equally with Public Schools, provide a liberal education. Probably in neither case is this perfectly balanced, the schools laying undue stress on languages and the Naval Colleges on the mathematical and scientific branches; but inasmuch as the Humanities take an important place in the work, our experience in teaching Physics is probably of more value to those concerned with Public Schools than with Technical Colleges.

Mr. C. E. Ashford, M.V.O., said: It may be worth while pointing out how far the conditions of the teaching with which I have been chiefly concerned in recent years differ from what you have already been considering in public schools and State-aided secondary schools, in order that anything I give as the results of the experiments going on at Osborne and Dartmouth in the teaching of science may be more intelligible. In the first place, the goal of the teaching is clearly defined in its earliest stages, which is not the case in almost any other scholastic institution. Speaking negatively, the aim most emphatically is not to get certain boys with credit or otherwise through an examination. The Admiralty provides the training for its cadets, it does its own examination, and it utilises the services of these boys for the rest of their lives. Therefore we work under an almost ideal state of things. There is no inducement to design or modify the training so as to suit a few selected individuals as an advertisement, while overlooking the claims of the remainder.

In the second place—and in this it is comparable with what should, perhaps, be the aim of a great many schools—the desire is to turn out men of action—practical men, not students primarily. After all, the object of being a student is usually that you may later on profit by the knowledge you have acquired and your practice in acquiring it. What I mean by men of action rather than students is men who will continue all through their lives to learn by doing things for themselves, by observing and experimenting, rather than by studying under teachers or in books. Naval officers must be many-sided, keen on everything, from machinery to strategy, and must possess or cultivate the power for instant decisions and for improvising means to meet novel conditions. They must have their knowledge handy; they must not merely know where facts are to be found. Some of these boys are to be specialists in various branches, but all of them will pass their lives as men of action. Moreover, they will be men who do not do things themselves, but make others do them. That may seem a subtle distinction, but it is much harder to direct the uninitiated in undertaking a task than to do it oneself. You will realise from this what kind of scientific training it is necessary to give at the naval colleges.

For instance, the measurement of simple physical quantities, which appealed to the early educators in science for various reasons, does not appear to be an ideal introduction to laboratory work. The beginner is bored by measuring a number of specific gravities and densities and so on. Still more strongly do I believe that boys are not ready to verify general laws at the beginning of their career in physics. What they want, then—I am speaking of boys between the ages of 13½ and 15—is to inquire into the behaviour of machines and apparatus. When that is done the boy will naturally seek the why and wherefore—in other words, the theory; and I venture to say that not only the naval officer, but the ordinary man in the street, will carry on both the process of acquiring knowledge of physics and the desire for it by having to use new machines.

There is another specific difference between the naval training and the training given in the majority of ordinary public schools in respect to the inclusion of a parallel and contemporary course in engineering workshops. It is essential that the men who are to take charge of those "boxes of engines," as battleships have been called, should be engineers in their very bones, and accordingly they go through a course of engineering from the age of thirteen. The reaction of this practical course on their theoretical science work is most beneficial; it provides a boundless wealth of illustration for those who are responsible for teaching the theory, and those who are teaching in the workshop are continually making demands upon the theoretical knowledge of the boys. It would appear likely to make the physics taught a great deal more applied than pure; it does so in the early stages, and my own feeling is that this is psychologically correct. The concrete and the applied is the correct material with which to provide a boy up to about fifteen. I believe the boy will naturally come to a systematic course later on, because he feels ready for it. As one effect of an early course of engineering, I would instance the teaching of mechanics. A science master at a public school, faced with the difficulty of starting boys on physics at fourteen with a blank ignorance of mechanics, may well decide to turn the difficulty by designing an introductory course of physics which does not involve any mechanical knowledge. There is very much to be said for this procedure; but if you have an engineering course running side by side with the physics course, both beginning at just over thirteen, you must grasp your nettle and attempt to teach mechanics at that age. That can be done satisfactorily, though it is slower, and the boys find it harder. My own belief is that the power to assimilate the principles of statics and kinetics is a function of age; but if you set the boy to deal with full-sized machines, to study their behaviour by taking four or five and thoroughly examining their mode of action, their velocity ratio, their efficiency, &c., and plotting the results—such machines as the screw jack, the Weston block, and so on—he will get a great deal of advantage out of them. He can go on later to the standard systematic course of statics, and at the age of about sixteen he is competent to undertake the very much more difficult questions of kinetics. These, I think, should be handled in the same way—that is to say, experimentally—keeping work, energy and momentum paramount, and kinematics as little prominent as you can. Kinematics should be treated only as it arises. The early treatment of mechanics is one of the difficulties which an engineering course introduces, but I believe that the reality and the concrete nature of the work and the interest which the boys exhibit in it, would alone justify having a course of engineering running parallel with the other.

The third point in which the conditions at Osborne and Dartmouth differ from those in public schools is that the course for every boy who enters is the same. I would support what Mr. Simmons has said—that it is the "educated citizens" we have to provide for rather than the specialist. Specialists have themselves damaged the training of boys in science because they have designed courses for them suited to future specialists, and not in the least applicable to those ordinary boys who will go through life—and these form the vast majority—not as specialists, but nevertheless as men from whom very serious and important work is expected. In the Naval training colleges, looking at a given entry of a hundred boys, we realise that perhaps half these boys will not live to reach high command in the Navy, but of the other half 25 per cent. will have been specialists of no mean order, and even upon the remaining 25 per cent. the fate of England may hang. I believe that the individual genius will not suffer at all from a course that is psychologically correct for the average boy.

Dr. Allen told me that it might be of some interest if I gave a very brief sketch of the methods by which we introduce the subject of electricity. What we have found to be most satisfactory is an unsystematic term's work at the age of about 14½, when both lecture and laboratory hours are devoted to a study of the behaviour of a jumble of the electrical apparatus and machinery which can safely be put into the hands of boys. This includes glow lamps, galvanometers of a simple electromagnetic kind, simple telegraphs, electric bells and motors, both toy and commercial sizes. There is no question of measurement whatever; they have not reached that stage. Let them deal also with dynamos, cells and electro-plating: this leads to the quantitative course by providing a measure of current. The introduction of potential difference is an obvious difficulty, but it can be overcome with surprising ease by taking sufficient thought.

I think I can give an outline of the process we adopt in a few words. We show a gold-leaf electroscope with the two leaves insulated from one another, and show the attraction between the gold leaves when a P.D. of about 100 volts is maintained between them. From that to an ordinary electrostatic voltmeter, as an indicator of a P.D., is a very short step. We proceed to define difference of potential by saying that a battery of n cells in series, each of V volts, gives a P.D. of nV volts; by building up a battery—which, of course, the boy has done before in his qualitative way—of a series of cells of known E.M.F. the voltmeter can be graduated. The boy thus acquires a qualitative and quantitative idea of a P.D. which is free from any danger of confusion with a current. Having, then, a graduated electrostatic voltmeter, and an ammeter graduated by electrolysis, Ohm's law can be verified. Then we introduce resistance as a ratio; and once you have got Ohm's law and your three practical units clearly in mind you can proceed extremely rapidly to quantitative questions arising from motors and dynamos. It is in such work, I believe, that boys are stimulated to learn the science of electricity, and where even your future specialist is going to profit. He gets at the age of sixteen a sense of reality which he does not get from the proof in the laboratory of various principles which are too abstract to interest him. A really rapid advance like that carries the boys at a run through and over various difficulties. A sixteen year old cadet deals unhesitatingly with fairly large motor-generators and their switchboards, making all connections to suit specified conditions, and he finds it logical and desirable to study such things as magnetisation curves and absolute units; they follow more naturally in that process than in the other. I do not for a moment wish to seem to belittle the systematic and logical course--it is vital and essential; but I hold that it is usually begun too soon.

I would mention one further point. I was under the impression that this might be an over emphasis on applied physics, tempting to the teacher because it interested the pupil without making demands on his mathematical powers, and so on; but I got one piece of evidence which rather went to show that this is not so. I calculated the Bravais-Pearson coefficient of correlation between science and mathematics in a considerable number of groups who pass out from Dartmouth at the age of 17, and I took the same co-efficients of correlation between science and engineering. It is curious that science and mathematics have a co-efficient of correlation of 0·81 and science and engineering of 0·78. There is, therefore, a tendency for science as taught even on these lines to be more closely correlated with mathematics than with engineering, so I am inclined to think that such an experiment as this, though carried out under special conditions, may be of interest to those chiefly concerned with theoretically pure physics.

*Physics in State-aided Secondary Schools.** *By* A. T. Simmons, *B.Sc.*, *A.R.C.Sc.*

I gladly avail myself of the opportunity of directing the attention of the Physical Society to some aspects of this wide subject which have impressed me in my work of inspecting the teaching of Science in Secondary Schools, the larger number of which, it should be said, are Schools receiving financial aid from the Board of Education.

In the schools to which reference is here made the age of nearly all the pupils ranges between nine and seventeen years. In most of the boys' schools and some of the girls' schools the attention of the pupils from twelve to sixteen years of age is given to the study of experimental Physics and Chemistry, and in most of the schools Physics and Chemistry are both studied in each of the four years under consideration. The average amount of time devoted to Science may be fairly put at four hours a week throughout the course. It is often less than this in the first year and more during the last year of the course. The general rule is to divide the time equally between Physics and Chemistry, though in some schools one subject only is studied during the last year, as external examinations are being prepared for. The present discussion is concerned only with the instruction in Physics.

The most common practice still is to devote the first year to preliminary measurements, such as those of length, area, volume and mass. More enlightened headmasters are, it is true, beginning to call much of this work Practical Mathematics, and to transfer it to the Mathematical course, and to make the Mathematical staff responsible for it; but, so far as my experience goes, this wise plan is even yet the exception rather than the rule. The second and third years are most commonly given to easy experimental work in hydrostatics, statics, dynamics and heat. In some schools a few experiments in light may be introduced in these years, or perhaps a few in electricity; but these cases may be regarded as exceptional. Pupils in the fourth year are commonly preparing for external examinations: hitherto it has been for a Matriculation Examination, and in the future it will be for the First General School Examination imposed by the Board of Education. The authorities—generally the Universities—who conduct these examinations have hitherto divided Physics up into a number of subjects, the divisions adopted being different in the case of different Universities, and Candidates generally offer one division of Physics only for examination purposes. In the case of most candidates these divisions are either (*a*) Heat, Light and Sound; or (*b*) Electricity and Magnetism.

Now most of the pupils leave school when this examination of matriculation standard has been passed, though a select few stay on for a further one or two years' study, and then have the opportunity of studying those branches of Physics to which as yet they have received no introduction.

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* Communicated before the meeting.

It is thus seen what the average boy or girl leaving these secondary schools has done in Physics. If, as is often the case, he leaves school before taking the fourth year of the Science course outlined above, or even if he first takes the General School Examination and offers Heat, Light and Sound, he passes out into the world completely ignorant of Electrical Science. He has studied Physics at School, forsooth, and has not even the most elementary knowledge of the manifold applications of electricity in human affairs.

Even if he has offered Electricity and Magnetism in his General School Examination, as schemes are at present arranged he has few opportunities of gaining an elementary acquaintance with the applications of Electrical Science to the industrial arts. Whatever he may or may not know of Electricity and Magnetism, it is certain either that his knowledge of Heat and other engines, &c., and of the phenomena of Light and Sound, is of the scantiest or his ignorance of them is complete.

The fact seems to be that hitherto school courses of Physics have been designed by men who have taken it for granted that all such work done in school is merely preliminary to a fuller course which will be entered upon after school days are over; that all school pupils who offer Science at the Matriculation Examination will continue to study the subject through the Intermediate and Degree stages of the University. But a very small fraction only of the pupils proceed to colleges of University rank and continue the study of Science in this way; and the teaching of Physics in schools will not be satisfactory from the point of view of the average boy or girl until it is recognised that the school course must be complete in itself, and that the knowledge the pupils gain there represents for the large majority all they will ever learn of Physics or any other branch of Science.

The task before the Physical Society is therefore clear. It should decide: what parts of Physics is it of imperative importance that every educated citizen should know, and what steps should be taken to make it easy for the secondary school pupil to acquire this knowledge at school?

I suggest that one of the first improvements for which the Physical Society should work is the substitution of a more general course of Physics—including the essentials of its various branches—for the more detailed and quantitative study of a few constituent parts of Physics. It must be understood, however, that this substitution will never be effected until the University authorities are willing to accept for their Matriculation Examinations such a general course of work as I have adumbrated in place of their present more specialised syllabuses in separate branches.

Another matter of almost equal importance is so to arrange the young pupil's introduction to the study of Physics that full use is made of the enthusiastic eagerness with which he first enters the physical laboratory. The boy of twelve of whom I am speaking comes generally from a course of Nature Study, where, if he has been well taught, he has handled and observed plants and animals. He may also have had some manual work and handled tools. He comes to the Physics Master enamoured with the idea of doing things for himself. He has learnt, moreover, to compare his work in Nature Study, and his experience of tools, with the formal work of the mathematical classroom, and Mathematics has no doubt suffered from the comparison. And what is provided in Physics in most schools to feed this young enthusiasm? The youngster is set to measure lengths in inches and centimetres, to find a value for π, to measure areas by counting squares, and so on. Instead of handling simple apparatus and *doing interesting things*, he finds himself working over again in a slightly different way problems with which he is or has been concerned in the Mathematics classroom, and instead of a change of occupation he feels he has only secured a change of room. To obviate this disappointment, the practice might well be that exercises which require only paper and simple mathematical instruments, and can be done equally well in an ordinary classroom, should be transferred from the Science Course to the scheme of Mathematics, and that the work of the Physical Laboratory should begin where the use of water and the balance are necessary.

Care must be taken, too, to provide the young beginner with variety and interest. Measurement may be easily overdone in these early stages. Surely it is possible in the first year at least to have a minimum of such accurate measurement, and to introduce instead a succession of everyday topics like pumps, syphons, floating bodies, and so on, the principles of which could be studied from working models.

And in every year of the course the teacher must strive to maintain the interest and to introduce variety. Of course, there must be sufficient practice in measurement in later years; but primarily it should be remembered that the needs of the ordinary boy whose work in Physics must be completed at school have to be borne in mind, and that if he is to gain a general idea of this wide subject only a strictly limited time can be given to any one branch

This argument suggests that in the future more use must be made of experimental demonstrations by the teacher, and it would be of service to Science Masters if the Society could indicate what subjects should—from the point of view of the place of Physics in a general education—be selected for individual experiments by the pupils themselves, and those which should be reserved for demonstration by the Master.

Mr. A. T. SIMMONS, B.Sc., A.R.C.Sc., Inspector of Secondary Schools for the University of London, said: Mr. President, ladies and gentlemen, I propose to be as brief as I can. I have summarised my remarks in the printed abstract which has been distributed already. I shall now try to index them. I think most of the teachers present came imagining that they were going to get a great deal of help in teaching physics out of the Physical Society. I am anxious that they shall not be disappointed, so I propose to formulate very briefly two problems to be left with the Physical Society for their more leisurely consideration. My knowledge of the teaching of physics has been obtained chiefly by watching the teaching in schools, those aided by the Board of Education, for the most part. I think I may summarise very rapidly what goes on in these schools. The age, roughly, varies from nine to 17. Physics is taught between the ages of 12 and the leaving age. In the first year of the teaching of physics the pupils are subjected to the inevitable fundamental measurements; in the second and third years they are given a little statics, hydrostatics, heat, and sometimes not very often a little light ; and, if you get a more original teacher, there may be just a suggestion of electricity. Then the fourth year arrives, and, it being a State-aided school, an examination begins to loom in the near distance, and the pupils cannot go on with their general course of physics because the examination is conducted, not directly by the Board of Education, but for the Board of Education by the universities, and the universities have not, it would seem, a very intimate knowledge of what goes on in the schools. The first examination is called the First School Examination, and it has to serve two purposes. It has to convince the Board of Education that the work in the schools which have been aided by them has been satisfactorily done, and, in the second place, it has to find out whether the work has been suitable to serve the purpose of matriculation—that is, as an entrance to a university course. Now notice the condition of things carefully. The university does the examining, and in nearly every case it prescribes the syllabus, and yet it knows apparently very little about the work in the schools ; but it does know what future work is required of the student who enters one of the colleges of the university. So the university authorities lay it down that for matriculation the pupil must offer either Sound, Light and Heat, or Electricity and Magnetism. And what is the result ? The result is specialisation either in Sound, Light and Heat or in Electricity and Magnetism. Mechanics is, it is true, sometimes taken, but never really as a branch of physics, only as a branch of mathematics under the direction of the mathematics master who performs no experiments. These boys, after they have got through the examination, leave school at about 16½ or 17. Now, surely here is something for the Physical Society to contemplate. The pupils' knowledge of physics, if they have taken Sound, Light and Heat, has included no mention of Electricity and Magnetism. They cannot put in a fuse, they cannot mend an electric bell, they do not know anything about wireless telegraphy or electric traction. On the other hand, if they have taken Electricity and Magnetism instead of Sound, Light and Heat, they know nothing about Sound, and very little about Light. Ought it not to be possible —is it beyond the powers of the Physical Society—to suggest a general course of physics and to indicate what are the fundamental facts and principles that the ordinray intelligent well-educated person ought to know, and could not they persuade the universities to let teachers submit a syllabus of a general course of Physics, and allow the matriculation examination to be passed in that ?

I ask you now, in the second place, to bear in mind that the children who come to these schools usually arrive at the age of nine. They begin the study of science as soon as they arrive. My experience is that they take up Nature-study in a thoroughly practical way, handling plants and animals, drawing them, and really get to know something of the subject ; and, besides this excellent work, the boys go—a great many girls, too—into the workshop and learn something of tools ; and there they hear that when they get to the age of 12 they will have the privilege of going into the physical laboratory and starting the study of physics. They *really* think it is going to be a great privilege, and in due course they get there, and are, as I have said, put on to those inevitable fundamental physical measurements. They start measuring lengths in inches and centimetres, measuring areas by squared paper and so on; and they soon come to see that they have been humbugged; they find that they have done the work before, only it was then called arithmetic! For in good mathematical teaching the pupils are introduced to measures of mass, length, area and volume in quite a practical way, and they are put to mark time for a whole year! They say, "We have not changed the subject, we have changed the room." They came to the Physics teacher absolutely brimful of a desire to learn physics, and you have done your best to choke them off.

I have a rough rule that I apply as to how the study of physics should begin. I always say, "All the practical work you can do in the ordinary class-room you can safely call mathematics; but when it is necessary to use water and a balance and there is a chance of making a mess, it is a case for the physical laboratory." Put the boys on to use working models of pumps, syphons, simple machines almost at once, and you will arouse an immediate interest which it should not be difficult to foster and maintain.

Prof. F. Womack, Bedford College, said: At this late hour I shall only keep you a very few minutes. My outlook on the subject is necessarily a good deal narrower than that of several of the speakers who have preceded me. The students with whom I have to deal are of two classes—men students going in for medicine, and women students, who, in the main, are going to take up the teaching of science. As regards the former, at the present time they enter at about the age of 17½ to 18, the age of entry being just now a little younger than it used to be. I have for some years past taken statistics of the knowledge of physics possessed by these students, and I find that during the last four or five years no less than 34 per cent. have had no previous training whatever in the subject. They were brought up in school entirely on the classical or the modern side, and are destitude of physical and frequently of chemical knowledge. The choice of a career in the case of these lads has often been left to the last moment. The parents have not decided what they should do with the boys, or, perhaps, they have decided at the very last moment that the medical profession is the only thing they can put them into. No doubt, it is still the case in a large number of secondary schools that there is a great predominance of the teaching of classics, and the boy who tries to go over to the science side is at once stigmatised as of a lower intellectual type Of the remainder, a few have done a little heat and a little geometrical optics. They have worked evidently from a narrow university syllabus, and with hardly any exception they have had no mechanical foundation except those dry-as-dust linear and areal measurements. They have had nothing to do with measurements of acceleration, with the measurements of the ballistic pendulum, or friction. I feel strongly that the teaching of mechanics in the schools should be in the hands of physics masters. It should not be handled by mathematical masters. In some schools the difficulty is that the master has to teach both subjects. I was very glad to hear Sir Oliver Lodge's suggestion that the teaching of science should be humanistic. Only a few months ago, speaking to the Association of Headmistresses, I made the same suggestion. It would always be possible to make the teaching of physics and mechanics in a large town biographical and humanistic. One could show students in London where Davy, and Faraday, and Boyle worked, where Hawksbee lived, and so on. With regard to the teaching of girls, still fewer of them have had any prevous training in mechanics; the teaching of science is delegated as a rule, to the assistant mistress, who is expected to be cognisant of physics and mathematics and Scripture, and not infrequently of botany as well! It would be a gain if the student of mechanics and physics at school could be freed from any syllabus whatever. I realise that there is always pressure being brought to bear upon masters and mistresses to allow youths to go up for examination, but if the examinations could be rendered as far as possible free from any association with the cut-and-dried syllabus of university courses, it would be enormously to the gain of the students themselves, and they would come up to the colleges with their interest maintained.

A letter of apology for inability to attend and take part in the discussion as promised was read from Mr. G. F. Daniell, of the Education Department, London County Council; and the Paper by Prof. T. P. Nunn, of the London Day Training College, was taken as read.

*The Training of Teachers of Physics.** *By Prof.* T. PERCY NUNN, *London Day Training College.*

It is hardly possible to deal usefully with this problem without indicating one's position with regard to a prior question: What is the aim of Physics teaching in schools? Let me say, then, that it does not seem to me satisfactory to define that aim either as the communication of a certain body of knowledge or as a certain type of "mental training." Physics is more than the sum total of known physical truths and physical methods. It is a historic way of intellectual life, a living and growing tradition of interest and inquiry which has for centuries been one of the main currents in the stream of Western progress, and is one of the chief constituents of present-day intellectual activity. Our object in teaching physics as a branch of general education should be to initiate the pupil into that way of life, to put him to school to that great tradition; in short, to make him feel what it is to be, so to speak, inside the skin of the physicist, sharing his interests, ideals and outlook on the world, learning in a simple way to use his tools, and tasting something of his sense of joyous intellectual adventure.

The first requirement in the training of the teacher is, I suggest, that he shall have learnt Physics in this sense himself. It is by no means always satisfied. Even graduates who have taken respectable places in the Honours lists too often leave the university with a narrow, pedantic and lifeless knowledge of their subject which is an inadequate basis for school teaching. Their knowledge is carried as an external burden, instead of being a genuine organ of their intellectual life. They may know physics, but they have not *lived* it. It is beyond my province to inquire into the origins of this serious defect. I venture however, to think that it will be remedied only as the aims of school teaching and university teaching become better defined and more clearly delimited; the former becoming less academic and more broadly "human," the latter losing the character of a training for success in a competitive examination.

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* Communicated before the meeting.

In the second place, it is necessary for the teacher to have not only a technical but also a critical or reflective knowledge of his subject. The attitude of the young graduate towards the concepts and hypotheses of Physics is, as a rule, naive; he takes them at their face value, never having had occasion to consider how much they contain of convention, symbolism and metaphor. For the future engineer such considerations may be superfluous; his use of Ohm's law, for instance, will not be prejudiced even if he should not only speak but think of electricity as "juice." But the case of the teacher is different. His business will be to use scientific ideas in building up his pupils' minds; he needs, therefore, to understand the true nature of the materials with which he is to work. Moreover, scepticism of the instruments of scientific progress (I adapt a phrase borrowed from Mr. H. G. Wells) is not merely a tiresome habit of impertinent metaphysicians; it is a vital part of the business of science, though not one in which every man of science need be interested. The teacher's preparation should include, therefore, a critical study of the history and nature of Physics in the spirit exemplified in Mach's famous work on mechanics and his less well-known book on heat—that is, he should study the psychological situations in which the chief notions of Physics arose, and should trace the main steps in their development, his constant object being to determine the significance of the historical facts as stages in man's perennial struggle to extend his intellectual control of physical phenomena. Incidentally, he should gain from such inquiries a sound elementary philosophy of science, many valuable hints for teaching methods, and an intimacy with the heroes of Physics which will often enable him to give a desirable human touch to his lessons.

Next comes the professional training in the narrower sense of the term. This will, of course, include an apprenticeship to the practical arts of exposition, class management and laboratory management served under competent supervision, as well as opportunities for observing accomplished craftsmen at work. But a liberal course in methodology is, to say the least, equally important. By "methodology" is meant a discussion of the distinctive aims of science teaching and of its place in education, the proper scope and character of the curriculum in differing circumstances, the principles that should determine the order and methods of treatment at different ages of the pupil, and a comparative study of the best methods of teaching the more important items in the Physics course. To set down this bald catalogue is to give a very inadequate idea of the value of a well-conceived course in methodology. It is impossible to expand the items here, but I may refer to Section IV. of the recent B.A. Report on Science Teaching for a fuller indication of the contents of one important corner of the field covered by the term.

The practical questions where and how the professional training should be given have occasioned much difference of opinion. The Board of Education recognise two rather sharply contrasted arrangements: The training may be given either entirely in a secondary school or in a training college. In the second case it includes teaching practice under supervision in a secondary school. It is difficult to see how either plan can be really satisfactory. The first may promise "quick returns" in superficial efficiency, but cannot guarantee, as a rule, the liberal grounding in the theory of his profession which every teacher ought to have. The second plan suffers from the opposite defect; it does not, as a rule, secure that the student's theoretical studies shall be adequately backed with practical work or pursued in a sufficiently practical atmosphere. Sir J. J. Thomson's Report advocates a middle course; it proposes that the student shall spend one term in a training college or university training department, and two terms as a student-teacher in a secondary school. This compromise, which appears to have been recommended largely in view of the needs of the residential public schools, has its own weaknesses, of which the most obvious is a failure to provide for effective correlation between the theoretical work of the training college and the practical work of the school. Its strength is that it recognises the necessity of combining the two factors which the Board's schemes divorce. Training colleges have as yet secured only a precarious reputation in the secondary school world, but the Report is undoubtedly right in the view that they have a function that cannot generally be exercised in a secondary school. They should be to the teaching profession what the Staff College is to the Army: centres where the experience of the profession finds its clearest and most conscious expression, and is formulated for general use, laboratories of pedagogical research and clearing houses of educational ideas, foci of educational thought and enthusiasm.

It is worth considering whether the analogy of the Staff College might not well be followed in recruiting the *personnel* of the training college; whether, that is, some of its teachers should not be schoolmasters or mistresses whose qualifications include aptitude for reflection upon professional principles as well as notable practical skill and experience, who would be invited to withdraw for a period from the busy routine of school life and take a share in forming the next generation of their colleagues. But whatever may be the value of this particular suggestion, I am convinced that the way of wisdom with regard to training colleges is not to suppress or to ignore them, but to take serious pains to strengthen them for the better performance of their indispensable duties.

Mr. J. Nicol, B.Sc., Northern Polytechnic, Holloway, said: The course of science followed at the average secondary school has been very ably described and criticised by Mr. Simmons in his contribution to this discussion. The main fault that he has to find is that too little ground is covered, so that the boy leaves school entirely unacquainted with certain branches of the subject. This, I consider, is due to the object which has been aimed at in shaping the science courses. Professor Gregory has quoted from the report of the Thomson Committee two of the advantages to be gained from an education in science—(*a*) training in observation and reasoning, (*b*) the acquisition of directly useful knowledge; but he omits to mention the advantage which the Committee put first—namely, that "it can arouse and satisfy the element of wonder in our natures." We may say that science teaching of the best type will satisfy, and thereby stimulate the curiosity of the boy. It will in many cases provide him with a hobby for his spare time, and should frequently create an interest in scientific progress, the pursuit of which will serve as an intellectual recreation throughout life. Unfortunately, the first of these aims (training in reasoning and observation) has been allowed to overshadow the others in the preparation of schemes of science teaching for schools As a result, the greater portion of the time is spent in the laboratory, and the exercises there are arranged to form a progressive course, and parts of the subject not reached by the course are comparatively neglected.

Take, for instance, heat as it is taught in the majority of the schools. The measurement of temperature, of coefficients of expansion of liquids and gases, and of specific and latent heats is well done, because it is easy to arrange a series of experiments that the boys can do individually. In addition, these experiments yield definite numerical results, which enable the master to check the accuracy of the work and assess its value in marks without much trouble. Other parts of the subject, such as the relation of change of state to pressure, the transfer of heat, and the conversion of heat into work, which are quite as important and have quite as many applications to everyday life, are comparatively speaking neglected. Even when the mechanical equivalent of heat is dealt with the treatment is usually very academic, and the steam engine is hardly mentioned.

In light, again, the laws of reflection and refraction, and the formation of images by lenses and mirrors, are subjects that lend themselves to individual experiments with quantitative results. On the other hand, the subject of colour and the effects of mixing pigments and lights of different colours, with their important applications to colour printing, are hardly dealt with at all.

In my opinion the cure for this fault is to be found in making a much wider separation than is customary between the laboratory work which the boys do themselves and the lessons at which experiments are shown by the teacher. The time given to the former should (supposing no extra time is allowed for science) be considerably cut down. That this can be done with advantage in the ordinary school, where more than half the total available time is now spent in the laboratory, becomes obvious, when we remember that Mr. Ashford has told us that at Osborne and Dartmouth, where the instruction is intended to be of a particularly practical type, only one-third of the time given to physics is spent in the laboratory. The time thereby saved should be used for the purpose of short lectures, illustrated by what may be termed "pretty" experiments—that is, by experiments that are qualitative rather than quantitative in character. In addition, there should be lantern slides illustrating the applications of physics to everyday life and to industry. Everything should be done to make these lectures interesting, and the boys should be encouraged to read as widely as possible in connection with them. Books approximating to the science reader rather than to the matriculation text-book type should be supplied, and several books should be read through rather than one exhaustively studied. The treatment of the subject in the lessons should
ive rather than deductive, so that the boys' general knowledge
creased with examples that satisfy their curiosity, and then the

general principles underlying the applications can be brought out. This is preferable to the present practice of attempting, first, firmly to fix the underlying principles, only introducing the applications as illustrations of these if time permits; or, if time does not permit, leaving them out altogether, in the belief that when, later on in life, the boy becomes acquainted with the applications he will remember his principles well enough to apply them.

If the physics work is so divided it may with great advantage be co-ordinated with the rest of the school work, so that the laboratory course gives practice in mathematics, while the lecture course affords material for English composition. This latter point is of great importance, for it may be said that the treatment outlined and advocated above is that which was in use twenty years ago in those schools which took any interest in science teaching. Then the science lesson was regarded by the majority of the boys simply as an opportunity for slacking, and the failure of this old teaching led to the introduction of the heuristic method, in which each boy was supposed to discover everything anew for himself under the more or less skilfully concealed guidance of the teacher. A strict adherence to the heuristic method is now generally admitted to be unsatisfactory, because of the inordinate amount of time it requires, and it is recognised that the boy may frequently gain far more advantage from watching a carefully devised and prepared demonstration carried out by the teacher than from doing a less satisfactory experiment himself, provided that his attention is really held, and that he afterwards describes what he has seen and learned.

It must, however, be emphasised that the choice of a method of teaching and of a particular course of work is of subsidiary importance if a really good teacher is obtained. From this point of view the present method of selection and treatment of teachers is open to criticism. Fortunately, there are very few cases where a teacher who does not know his subject is asked to teach physics; but there is a tendency to go to the other extreme, and pay attention only to specialised academic qualifications in making a choice. At the present time, for instance, many secondary schools are trying to retain a proportion of their boys at school to do more specialised science work from the ages of 16 to 18. For this work it is considered necessary to have a teacher with a first class honours degree. In order to obtain this a man must have had for several years an extremely academic education, which does not fit him for work as a schoolmaster. Boys take a great interest in new applications of science to everyday life, such as steam engines, motor cars, aeroplanes, wireless telegraphy, X-rays and so on. In a secondary school there is no teacher of engineering, and the boy should naturally look to the physics master for help and suggestions for reading and experimenting in these subjects. For such work a less specialised training than that of the first class houours man in physics is more suitable.

The question of the training of the teacher has been specially discussed by Prof. Nunn; but in this, as in the training of the boy, there is too great a tendency to regard the matter as finished when the master leaves the training college or the boy the school. In the latter case we must, before all, aim at creating an interest, so that the boy will continue to learn from books and everyday life. In the case of the master, we must realise that physics is a living subject, and is at present moving forward as fast, or faster, than any other branch of knowledge. The teacher will, therefore, need to keep himself up to date, and at present he seldom receives sufficient encouragement to do this. Annual subscriptions to learned societies, payments of fees for advanced courses, the expense of attending, say, lectures at the Royal Institution or a British Association meeting, and the cost of books are in many cases beyond the means of science teachers, especially of those with a family. It would be in the interest of the school if the master were assisted financially in keeping himself up to date. A mere increase of salary does not do this, as it still leaves the choice of spending the money in other ways, and in these days of salary scales for everyone the return to the teacher on money spent by him in keeping thoroughly efficient is somewhat uncertain.

To sum up, the teaching of physics stands in need of broadening and revivifying. This can best be done by endeavouring to keep it in touch with everyday life, and so to defeat any attempt to standardise it and use it merely for the purpose of giving a training in logical method in the way that geometry was used in the days when it appeared in the school time-table as Euclid.

A Physics Laboratory for a Secondary School.

Mr. E. Smith, B.Sc., Leyton Secondary School, said: Mr. President, I should like to present the subject from the viewpoint of a master actually engaged in teaching in a secondary school, where all the pupils have to go through a course of physics from eleven years of age to sixteen

Efficient teaching presupposes, firstly, the existence of a proper scheme; and, secondly, facilities for working it successfully. The provision of a proper scheme is generally easy. The authorities, the headmaster and the teacher are all in sympathy, and the capable teacher is given a free hand. The facilities may be classed under two heads: (i.) Laboratory; (ii.) teaching facilities. These last two matters, which include questions of finance, organisation of a curriculum, the actual teaching time of the master and the time available for correction, preparation and repairs are apt to cause divergent views amongst governors, headmasters and teachers.

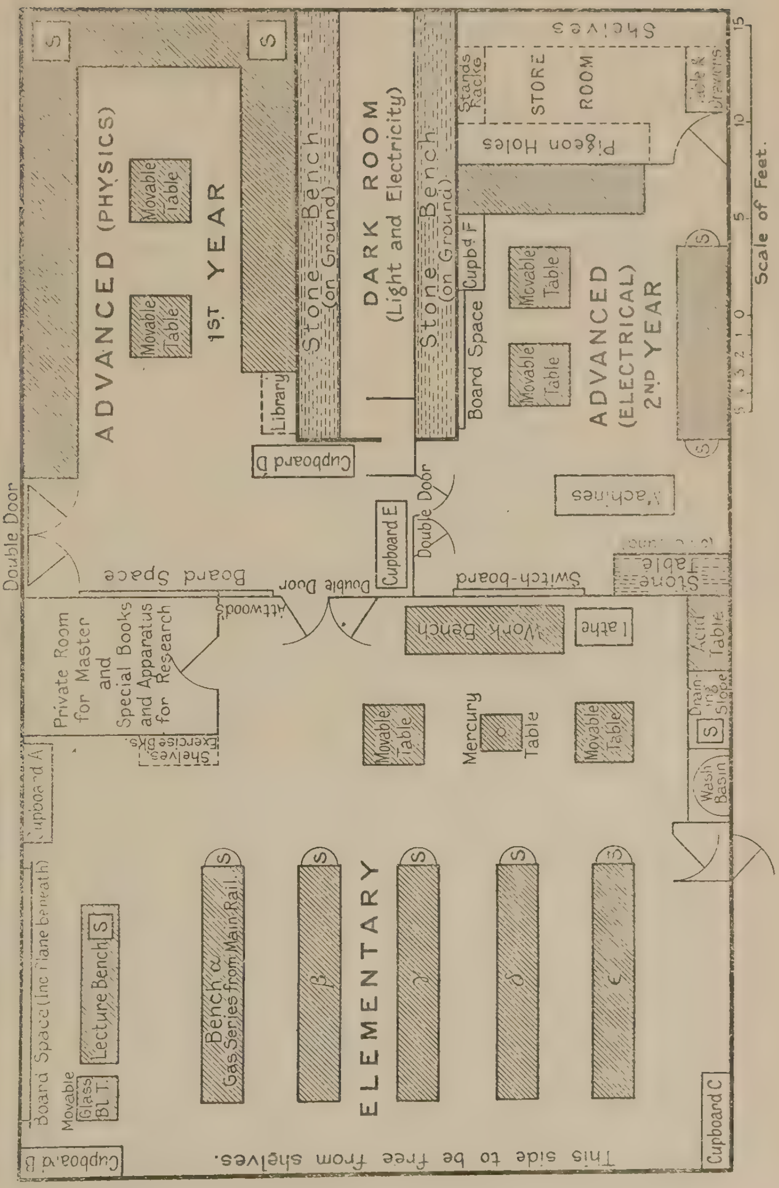
With regard to laboratory facilities, the course of teaching for younger boys and girls must be mainly qualitative, for one of the most important ends in elementary teaching is to make the young student form accurate mental pictures.

I show on the lantern screen (Fig. 1) the design of a laboratory measuring 60 ft. by 36 ft., and divided into two sections—namely, elementary, for students up to 16 years of age; advanced, for students from 16 to 18 years. The course has in the last year of the advanced section an electrical bias, which has been rendered necessary, I believe, by modern developments.

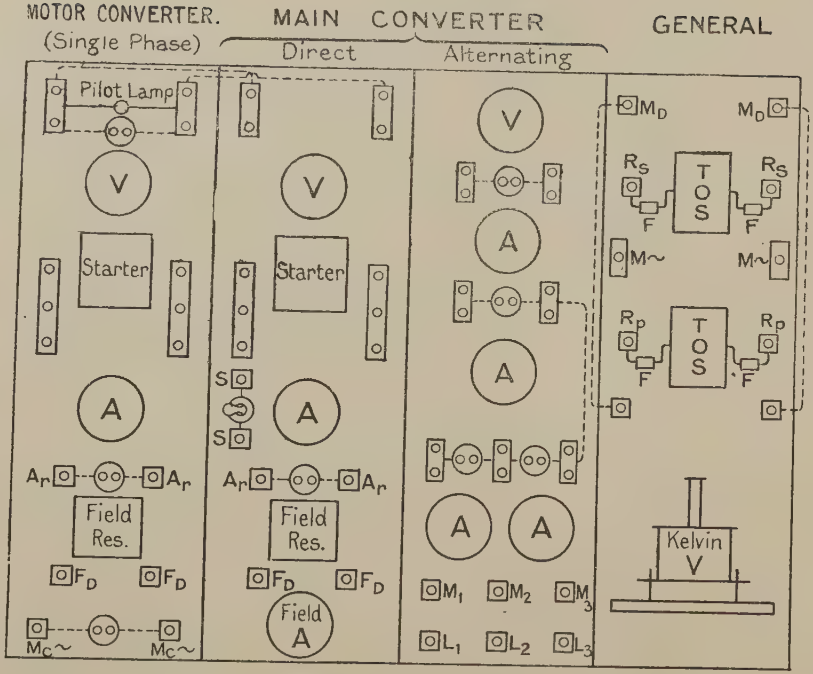
The arrangement of the elementary section should be such as to provide for rapid alternations from practical to lecture work, and the

Suggested Laboratory for Complete Course.
(36×60 ft.)

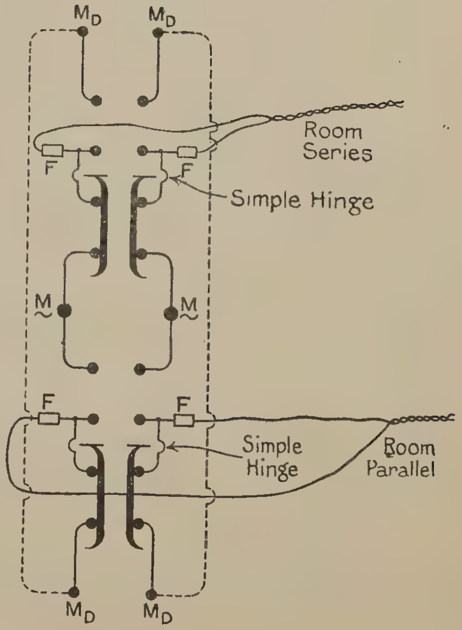
PHYSICS.



SWITCHBOARD.



Throw-Over Knife Contact Switch.



benches are arranged to suit that purpose. Stools are provided in the gangways, yet the students can all face the teacher at any moment. If you take a simple experiment, in frictional electricity for example, it will not take more than five or ten minutes to perform, yet you will require to consider the results in detail and connect them, if possible, with every-day phenomena

A large amount of free space has been allowed for experiments of a bulky character, such as for wave motion and certain sections of mechanics, and one wall has been left free for other mechanical experiments.

The advanced laboratories have provision for more continuous work. Each laboratory, elementary or advanced, should have its own electrical circuit, with a "series" connection, if possible, to a direct-current town supply; with suitable single-pole terminals on each bench coming from a bank of lamps which supplies the whole room. This arrangement does away with the wasteful and untidy use of primary and secondary cells. Secondary schools have fairly long holidays, and secondary cells are liable to deteriorate.

A dark room is essential for optical and galvanometer work. To avoid the consequences of interruption, it is better to have a blackened entrance stopping direct rays of light than to have a doorway.

The advanced electrical laboratory should be fitted with "series" and also with "parallel" circuits that can be instantly changed over from direct to alternating sources when required. The switchboard (Fig. 2) should be governed by a foolproof switch, and all the connections should be made on the surface by the students. The governing switch avoids the necessity for constant and close supervision by the master. In an electrical laboratory there is much scope for the creation of apparatus for abolishing bad contacts and the provision of subsidiary sources of E.M.F., and also many opportunities for using commercial apparatus without impairing the educational efficiency of the course.

The machines advised for a flexible installation with a direct-current supply are:—

i. A single-phase rotary converter that may be coupled to

ii. A rotary converter having six slip rings; and

iii. A small three-phase induction motor with a wound rotor having external connections to a resistance.

The designs given show many smaller details. They allow for a provision of fundamental necessities, and yet permit the physics master full scope for original adaptations in his course.

With regard to the provision of teaching facilities, there is one point I should like to raise. In the science teaching in the State-aided school the amount of time allowed to the master for preparation, correction, epairs, etc., is, I think, generally inadequate. I should estimate that in an advanced section half of the total time would be certainly necessary, whilst in the elementary section one quarter would suffice. This point requires much consideration at the present time.

Mr. W. R. Cooper (communicated) was glad to see that there was a consensus of opinion in favour of making physics interesting. This, he thought, was most important If it were not too unorthodox, he would have liked to have seen the meeting addressed also by some representative schoolboys. The trained physicist of middle age was apt to forget the boy's point of view. It would be well to draw up two courses of instruction, one being for boys of, say, 11—14 years, and the other for older boys. The object of the junior course would be to arouse interest, pure and simple, and to enlarge the scope of the mind; measurements and principles would be excluded. For the older boys measurements might be introduced. It was very important to give instruction to the younger boys because their minds were very receptive, but it was essential to interest them. Nothing less inspiring could be imagined than, say, the determination of specific gravity. The small boy could see no use in it; he probably became weary of what he considered useless and uninteresting, and preferred to dabble in chemistry, in which he could see something going on. Many preparatory schools were probably at fault in giving no instruction in physics.

Mr. F. B. Stead, H.M. Inspector for the Board of Education, said: Mr. President, I was very glad to have the opportunity of being present at this meeting. If I venture on any observations I hope it will be distinctly understood that I am speaking for myself alone, and am not putting forward views officially endorsed by the Board of Education. The Board has not formulated any view as to the methods of science teaching in secondary schools, save that in 1909 some observations did appear in the annual report of the Board—a document, I am afraid, which is not very widely read. Among the many interesting Papers which were circulated I turned naturally first of all to the Paper by Mr. Simmons on "Physics in State-aided Secondary Schools," and I found myself in agreement, broadly speaking, with what he said as to the general scope and conditions of work in these schools. I would only plead that if there is a rather depressing uniformity such as he seemed to indicate in the work of these schools, that uniformity is not due to any efforts to secure uniformity made by the Board of Education. The uniformity, so far as it exists, is due to certain paramount conditions by which the teaching of all subjects, including science, is affected, namely, examinations, the general teaching tradition, the previous education of the teacher, and, last, but not least, the text-books, which tend naturally to affect the teaching in the school. With regard to the time to be given to science in secondary schools, Mr. Simmons says that the time devoted to science may be fairly put at four hours a week throughout the course. I think that is really a high estimate, certainly for girls' schools. If he means four periods, and not four hours, I rather agree. With regard to the preliminary work in mensuration I do not think it does absorb the quite inordinate amount of time which was at one period given to it. I quite agree that this work should be done by the mathematicians. The difficulty is to get the mathematicians to do it. I may say that I myself and my colleagues have been campaigning for the last 8 or 10 years at least—with a certain amount of success—in favour of limiting the amount of time given by the science teacher to that dull work of mensuration. This kind of work is, however, to be found not only in the State-aided schools, but also in one or two public schools of my acquaintance.

I should like to make one or two points respecting the teaching of physics, which have either not been dealt with by previous speakers, or which might be emphasised still more than they have been this afternoon. First of all, I would say that the physics teaching is very much influenced by the desire of the physics teachers to utilise the school laboratory at all costs. It results from this that the physics course consists too often of a series of practical exercises, mainly quantitative in character, carried out in the laboratory, each exercise designed to be completed within the limits of a single lesson period of an hour or an hour and a half. It follows from this that the laboratory exercise that can be done in one lesson period tends to become the unit of teaching. That is a fundamental error. The exercises in consequence are often disconnected from one another, too little attention is given to the actual results, not enough time is left for discussion, alternative methods of arriving at the result are ignored, and, last and worst of all, the relation of the particular exercise to the larger subject to which it belongs tends to be entirely forgotten. The boys often unconsciously pursue a course of practical physics following, perhaps, some text-book of practical physics and get very little out of it beyond a certain facility in manipulation and the power to carry out instructions. In the second place, measurement, in the larger sense, tends to be thought of as an end in itself. I should like to illustrate. The first introduction of a boy to the subject of specific heat is the practical expression, "find the specific heat of copper." Of course, it is not an *introduction* to the subject of specific heat. It is no doubt important that the boy should be able to find out the specific heat of copper, but it is much more important that he should realise that there is such a property as specific heat. If you ask the boy what is the effect of solar radiation on the surface of land when that surface consists of sand or clay or snow, he will often be very much puzzled to give you an answer, in spite of the fact that he has done some determinations of specific and latent heats, and carried out one or two experiments on conductivity. That, of course, is not right. Again, every schoolboy finds the index of refraction of glass by one of two methods. If you ask him to tell you anything about the index of refraction of diamond you are not likely to get much of an answer; and if you go on to ask him how it is connected with one of the most characteristic properties of the diamond, you get no answer at all. All this shows how wrong it is to make measurement an end in itself, and how extremely important it is that the course of practical physics should be helped out by adequate discussion and attention to results, and should not consist of disconnected exercises.

Attention has been drawn to two views this afternoon concerning methods of teaching physics. One is the view of Mr. Ashford and Mr Bryant that you should begin with the machine and work back to the principle; the other view favours the opposite method of treatment, indicated by Sir Oliver Lodge. I venture to make this suggestion, that the difference—apparently a very marked difference between these two views—is greater in appearance than in reality, and that differences in method of teaching which are startling enough when expressed on the platform tend to disappear when one is face to face with the problem in the laboratory or the lecture-room. I think we should find that Mr. Ashford and Mr. Bryant, if we met them at home in their own laboratories and classrooms, would be quite well aware of the importance of logic in the teaching of science, and that they were not going quite wild with machines. I have ventured in the course of my remarks on one or two criticisms, but I should like to end on a note of appreciation of the good work which is done by many teachers of physics in our secondary schools.

Sir Oliver Lodge, replying on the discussion, said: Well, sir, it is very late, and the audience has diminished since I last spoke, but I think we must all feel that we have heard some very instructive remarks; certainly I feel that. There are, however, just one or two little points on which I may say a word in reply. In the first place some very minor points: There is the term "specific heat," which was often naturally employed by the last speaker. I often feel that we shall never get clear ideas on that subject as long as we use that term at the beginning of things. It is a slang term which we have grown accustomed to. It is an abbreviation for "specific capacity for heat," and the important idea is capacity. One speaker seemed to expect children to know about the refractive index and other properties of the diamond. I think children ought not to be able to answer questions like that. How many of them see diamonds? The students never see them in my laboratory!

The main thing that has been disagreed with in what I said in the opening remarks, is the point which was taken up in the very important observations of experienced teachers like Mr. Bryant and Mr. Ashford—namely, as to their preference for the analytic method. I should like to agree with them, and to a great extent I do agree in practice, but one must discriminate between a systematic course and a general experience. What interests the boys before they enter on a systematic course is the concrete reality, the machine itself. No doubt if this did not exist there would be no interest felt in the principles underlying it. And, therefore, I suppose, the two things ought to go on together, and ought not to be set in opposition to each other; but how intelligibly to dissect out the principles from the complex engine I do not know. I know that the engine is interesting; I used to be fascinated with engines; but I should expect a systematic course to begin with, and build up from principles and not with analysis of the complex thing.

A good deal has been said about experimental mechanics, and it has been stated that this ought to be done by the physicist and not by the mathematician. I do not quite know why; perhaps, only because the physicist will do it better. No doubt he will, because it is his business to do experimental things, but there are so many things in physics more worth his doing than elementary demonstrations either in geometry or in mechanics; and I confess I should like to see the mathematician have to do some experiments, and get in the way of setting the boys to do experiments, even when they are quite elementary ones for juveniles. Let him give them three points, and say, "Now draw a circle through them." Let them invent a method of drawing the circle through three points. That illustration must serve as an illustration for a whole heap of things; and similarly with mechanics, let them be treated not only in the abstract, but in concrete form. At Charterhouse my brother tells me this is now being done; experimental mechanics is now being taught by the mathematical masters, and I welcome it as being so good—for the mathematical masters!

The PRESIDENT said: The fact that we finish up this meeting not knowing whether mechanics should be taught by the physicist or by the mathematician, or whether teaching should begin with common objects and proceed to principles or the reverse, proves that there are some points which the discussion has failed to settle, but upon one point there is absolute unanimity, and that is that the course of physics provided in the schools should not be designed to suit only those who ultimately go on to the university, but to suit those who will get in schools the only knowledge of physics they are ever likely to possess

I ask the members here present to return their thanks to those who have taken part in the discussion, and to Dr. Allen, for having organised it so well. (Applause.)

REFERENCES.

Report of the British Association Committee on Science Teaching in Secondary Schools. (Offices of the Association, Burlington House, W. 1.) 1s. net, 1917.

Report of the Committee to Enquire into the Position of Natural Science in the Educational System of Great Britain (H.M. Stationery Office, Cd. 9,011.) 9d. net, 1918.

"Science for All," a scheme of work for Public Schools. (Association of Public School Science Masters. Hon. Sec., C. L. Bryant, M.A., "Ludlow," Harrow.) 5d. net.

The Society has to mourn the loss of Mr. W. Duddell, F.R.S., who for many years had taken an active part in the work of the Society. The Society also has to record with regret the deaths of Mr. Walter Baily, Dr. C. V. Burton, Sir W. D. Niven, F.R.S., Mr. Wilson Noble, Mr. S. T. Preston, Prof. G. Quincke, the Rev. P. R. Sleeman, and the Hon Sir James Stirling, F.R.S.

The Council has appointed representatives on the Nitrogen Products Committee under the Ministry of Munitions, on the Board of Scientific Societies, and on a Committee of the Röntgen Society for the discussion of points of interest to the X-ray industry. The Council have also appointed a Committee to consider and report upon the possibility of steps being taken to improve the professional status of the physicist.

The Treasurer's Report was read by Mr. W. R. Cooper.

The accounts for the past year show a less satisfactory position than usual, the expenditure exceeding the revenue by £48. 17s. 9d. The expenditure, however, includes a sum of £15. 15s. 10d. for secretarial expenses in respect of the year 1916, so that the debit balance, strictly speaking, amounts to £33. 1s. 11d.

The expenditure on printing is considerably more than in the previous year, and the donation to the S. P. Thompson memorial is an unusual item.

The unsatisfactory position, however, is really due to the fact that many Fellows are in arrears with their subscriptions. The balance sheet shows that the sum thus due to the Society at December 31 last was £219. 18s. 6d., which is very heavy compared with the corresponding figure of other years. Owing to war conditions and the absence of many Fellows on active service, this was to be expected to some extent; but even so the amount seems abnormal. As it is improbable that all the arrears will be realised I have thought it desirable to set off a reserve of £31. 10s. against the full sum.

The investments, which have been valued at market prices through the courtesy of Parr's Bank, have depreciated slightly below the figure in the last balance sheet.

Both reports were unanimously adopted.

THE TREASURER IN ACCOUNT WITH THE PHYSICAL SOCIETY, FROM JANUARY 1ST, 1917, TO DECEMBER 31ST, 1917.

INCOME AND EXPENDITURE ACCOUNT.

Dr.	£	s.	d.	£	s.	d.
Entrance Fees	10	10	0			
Subscriptions by Fellows	401	2	0			
,, Voluntary	16	16	0			
,, by Students	1	11	6			
,, Arrears paid	18	18	0			
,, Paid in Advance	2	7	6			
,, for "Science Abstracts" and Advance Proofs	10	2	6			
				461	7	6
Composition Fees				Nil.		
Dividends :—						
Furness Debenture Stock	11	19	10			
Midland Railway	30	10	0			
Metropolitan Board of Works	5	5	0			
Lancaster Corporation Stock	9	0	0			
New South Wales	6	13	6			
London, Brighton & South Coast Railway	19	5	2			
Great Eastern Railway	15	0	0			
India 3½% Stock	13	2	8			
Exchequer Bonds, 5%	20	0	0			
				130	16	2
Interest on deposit account				4	0	0
Sales of Publications (Fleetway Press, Ltd.)				158	7	9
Balance, being excess of expenditure over income				48	17	9
				£803	9	2

Cr.	£	s.	d.	£	s.	d.
"Science Abstracts"	274	16	0			
,, ,, Extra copies	2	16	6			
				277	12	6
Fleetway Press, Ltd. :—						
"Proceedings"	295	0	7			
Bulletin	13	13	4			
Distribution	46	18	7			
General	28	12	10			
				384	5	4
Periodicals	1	15	0			
Reporting	36	17	6			
Refreshments and Attendance	13	5	7			
Guthrie Lecture—Honorarium	10	0	0			
Royal Asiatic Society	2	2	0			
Petty Cash—						
Secretaries' Expenses (including £15 15s. 10d. for 1916)	28	1	6			
Treasurer's Expenses	1	14	8			
Bank Charges and Cheques		8	11			
Insurance	6	10	0			
				100	15	2
Donations—						
S. P. Thompson Memorial	25	0	0			
International Catalogue	5	16	2			
Conjoint Board of Scientific Societies	10	0	0			
				40	16	2
				£803	9	2

W. R. COOPER, *Acting Honorary Treasurer.*

Audited and found correct,

T. MATHER,
A. A. C. SWINTON } *Honorary Auditors.*

January 31st, 1918.

ASSETS.	£	s.	d.	£	s.	d.
Subscriptions in arrears	219	18	6			
Less reserve for subscriptions probably unrealisable	31	10	0			
				188	8	6
Investments (valued at Dec. 31) :—						
£533 Furness 3 per cent. Debenture Stock	277	0	0			
£1,600 Midland Railway 2½ per cent. Perpetual Preference Stock	734	0	0			
£200 Metropolitan Board of Works 3½ per cent. Consolidated Stock	164	0	0			
£400 Lancaster Corporation 3 per cent. Redeemable Stock	228	0	0			
£254 2s. 9d. New South Wales 3½ per cent. Ordinary Stock	218	0	0			
£500 London, Brighton & South Coast Railway Ordinary Stock	365	0	0			
£500 Great Eastern Railway 4 per cent. Debenture Stock	361	0	0			
£500 India 3½ per cent. Stock	315	0	0			
£400 Exchequer 5 per cent. Bonds, 1921	399	0	0			
				3,061	0	0
Outstanding Credit on Sales				59	3	10
Outstanding Credit (overcharge)				3	16	8
Stock of Publications (Treasurer's estimate)				220	0	0
Cash at Bank on Deposit				100	0	0
Cash at Bank, Current Account at Dec. 31	45	10	2			
Adjustment for outstanding cheques	3	12	0			
				49	2	2
Cash in hand (Treasurer's Petty Cash)					5	4
				£3,681	16	6

W. R. COOPER, *Acting Honorary Treasurer.*

LIABILITIES.	£	s.	d.
Life Compositions	1,880	10	0
Sundry Creditors	11	10	0
Balance, General Fund	1,789	16	6
	£3,681	16	6

Audited and found correct,

T. MATHER, } *Honorary Auditors*
A. A. C. SWINTON,

January 31, 1918.

LIFE COMPOSITION FUND.

	£	s.	d
151 Fellows paid £10	1,510	0	0
3 Fellows paid £15	45	0	0
5 Fellows paid £21	105	0	0
7 Fellows paid £31. 10s.	220	10	0
	£1,880	10	0

Audited and found correct,

W. R. COOPER, *Acting Honorary Treasurer.*

January 31st, 1918.

T. MATHER,
A. A. C. SWINTON, } *Honorary Auditors.*

After the customary votes of thanks, the election of Officers and Council took place, the new Council being constituted as follows :—

President.—Prof. C. H. Lees, D.Sc., F.R.S.

Vice-Presidents, who have filled the office of President.—Prof. G. C. Foster, D.Sc., LL.D., F.R.S. ; Prof. R. B. Clifton, M.A., F.R.S. ; Prof. A. W. Reinold, C.B., M.A., F.R.S. ; Sir W. de W. Abney, R.E., K.C.B., D.C.L., F.R.S. ; Prin. Sir Oliver J. Lodge, D.Sc., LL.D., F.R.S. ; Sir R. T. Glazebrook, C.B., D.Sc., F.R.S. ; Prof. J. Perry, D.Sc., F.R.S. ; C. Chree, Sc.D., LL.D., F.R.S. ; Prof. H. L. Callendar, M.A., LL.D., F.R.S. ; Prof. A. Schuster, Ph.D., Sc.D., F.R.S. ; Sir J. J. Thomson, O.M., D.Sc., F.R.S. ; Prof C. Vernon Boys, F.R.S.

Vice-Presidents.—Prof. J. W. Nicholson, M.A., D.Sc., F R S ; Prof. O. W. Richardson, M.A., D.Sc., F.R.S. ; S. W. J. Smith, M.A., D.Sc., F.R.S. ; W. E. Sumpner, D.Sc.

Secretaries.—Prof. W. Eccles, D.Sc. ; H. S. Allen, M.A., D.Sc.

Foreign Secretary.—Sir R. T. Glazebrook, C.B., D.Sc., F.R.S.

Treasurer.—W. R. Cooper, M.A., B.Sc.

Librarian.—S. W. J. Smith, M.A., D.Sc., F.R.S.

Other Members of Council.—Prof. E. H. Barton, D.Sc., F.R.S. ; C. R. Darling, F.I.C. ; Prof. G. W. O. Howe, D.Sc. ; D. Owen, D.Sc. ; C. C. Paterson ; C. E. S. Phillips, F.R.S.E. ; S. Russ, M.A., D.Sc. ; T. Smith, B.A. ; F. J. W. Whipple, M.A.

The President announced that Dr. R. S. Willows had resigned his secretaryship on leaving London for a post in the north. The Council had appointed Dr. H. S. Allen, M.A., in his place.

At the conclusion of the general business Prof. Boys vacated the chair, which was taken by Prof. Lees. The following Papers were read :—

1. "A Recording Thermometer." By Prof. C. V. Boys, F.R.S.

2. "The Primary Monochromatic Aberrations of a Centred Optical System." By Mr. S. D. Chalmers, M.A.

February 22, 1918.

Meeting held at Imperial College of Science.

Prof. C. H. Lees, F.R.S., President, in the Chair.

The following Papers were read :—

1. " A Note on the Use of Approximate Methods in Obtaining Constructional Data for Telescope Objectives." By T. Smith, B.A.

2. " A Suggestion as to the Origin of Spectral Series." By Dr. H. S. Allen, M.A.

March 8, 1918.

Meeting held at Imperial College of Science.

Prof. C. H. Lees, F.R.S., President, in the Chair.

The following Papers were read :—

1. " The Asymmetrical Distribution of Corpuscular Radiation from X-rays." By E. A. Owen, M.Sc.

2. " On 'Air-Standard' Internal Combustion Engines and their Efficiencies." By Prof. C. H. Lees, F.R.S.

March 22, 1918.

Meeting held at Imperial College of Science.

Prof. C. H. Lees, F.R.S., President, in the Chair.

The Fourth Guthrie Lecture was delivered by Prof. J. C. McLennan, of Toronto, who took as his subject " The Origin of Spectra."

April 26, 1918.

Meeting held at Imperial College of Science.

Prof. C. H. Lees, F.R.S., President, in the Chair.

The following Papers were read :—

1. "Notes on the Pulfrich Refractometer." By J. Guild, A.R.C.S.

2. "On the Accuracy Attainable with Critical Angle Refractometers." By F. Simeon, B.Sc.

3. *"Cohesion" (Fourth Paper). By Prof. H. Chatley.

* Taken as read in the absence of the Author.

May 10, 1918.

Meeting held at Imperial College of Science.

Prof. C. H. Lees, F.R.S., President, in the Chair.

The following Papers were read :—

1. "The Times of Sudden Commencement of Magnetic Storms." By Dr. S. Chapman.

2. "The Entropy of a Metal." By Dr. H. S. Allen.

3. "On Tracing Rays through an Optical System." By T. Smith, B.A.

June 14, 1918.

Meeting held at Imperial College of Science.

Prof. C. H. Lees, F.R.S., President, in the Chair.

A Discussion took place on "The Teaching of Physics in Schools." It was opened by Sir Oliver Lodge, F.R.S., and taken part in by Prof. R. A. Gregory, Mr. C. L. Bryant, Dr. T. J. Baker, Mr. C. E. Ashford, Mr. A. T. Simmons, Prof. F. Womack, Mr. J. Nicol, Mr. E. Smith and Mr. F. B. Stead.

June 28, 1918.

Meeting held at Imperial College of Science.

Prof. C. H. Lees, F.R.S., President, in the Chair.

The following Paper was read :—

"A New Method of Measuring Alternating Currents and Electric Oscillations." By Mr. I. Williams, B.Sc.

A Demonstration of Coupled Vibrations was given by Prof. E. H. Barton, F.R.S., and Miss H. M. Browning.

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